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AN ANT SYSTEM APPROACH TO STRUCTURE OPTIMIZATION OF POWER CELLULAR WITH DIFFERENT REDUNDANT CELLS

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Abstract

This paper uses an ant system (AS) meta-heuristic optimization method to solve the problem of structure optimization of power cellular systems. We consider the case where redundant cells are introduced to achieve a desirable level of reliability. The cells of the system are characterized by their cost, technology, capacity and availability. The reliability is defined as the ability to satisfy the consumer demand (battery load) which is represented as a piecewise cumulative load curve. The proposed meta-heuristic seeks for the optimal configuration of series-parallel systems cells in which a multiple choice of cells are allowed from a list of different technologies are available in the market. Our approach has the advantage to allow cells with different technologies to be allocated in parallel-series. To allow fast reliability estimation, a universal generating function method is applied.

Keywords: Ant System (AS), Optimization, Cells, Battery, Reliability.

1 INTRODUCTION

To provide a requirement level of system cells reliability, redundant cells are included. Engineers try always to reach this level with minimal cost. The problem in power cells systems concerning a natural objective function is to minimize the total cost of the system subject to reliability constraints. This problem is well known as redundancy optimization problem. It has addressed in many studies [1] [3]. These studies are usually concerned with the binary state case. However, power systems exhibit a multi-state behavior. In fact, when applied to power systems, reliability is considered as a measure of the ability that production systems cells meet the load demand (loading batteries), i.e. provide an adequate supply of electrical energy [5]. In this case, the effect of outage will be different for cells and different nominal generation of power capacity will also depend on consumer battery level. In fact the capacities of power system component should be taken into account as well as the consumer load curve. The redundancy optimization problem for a system with different cells capacities may be considered as a problem structure optimization. This problem is addressed in [6], where the basic approach optimization was formulated. In reference [4], a modification of the gradient method was applied for finding the minimal cost configuration of series-parallel power system structure. Cells of the system with different capacities and costs were considered, and demand was estimated using a load curve. The drawback of the approach adopted in [3] and [4] is that costs of cells are defined as explicit analytical function of their capacities and the same reliability index values are assigned to all the cells of given type, regardless of their capacity. In [2], a genetic algorithm approach is used as an optimization technique to solve the problem.

In this paper, we suggest an AS algorithm to find the optimal system structure by choosing the appropriate product (technology of a system cells) from a list of available cells in market for each type of technology. In practice, a variety of products are in fact available and each technology is characterized by its capacity, reliability and cost. Our objective is to select the optimal combination of cells used in parallel for all components corresponding to the minimal total cost subject to the requirement of meeting the demand (loading batteries) with the desirable level of reliability. The AS algorithm is inspired from nature like others meta-heuristic, e.g; simulated annealing, genetic algorithm, evolutionary strategy, and tabu search. The AS allows each component to contain cells with different technologies. To evaluate the reliability for arbitrary series-parallel system structure, a fast procedure is developed which is based on universal generating function (UGF) [4] [8].

The rest of the paper is organized as follows. Section 2 of the paper consists of a general description of model used and a formulation of problem. In section 3, we describe the reliability estimation method using the UGF technique. Section 4, describes the basic AS approach and its adaptation to the problem. In section 5, an illustrative example is represented. Conclusions are drawn in section 6.

2 DESCRIPTION OF SYSTEM MODEL AND PROBLEM FORMULATION

Let us consider a system cells containing n components connected in parallel series as sketched in (Fig. 1).

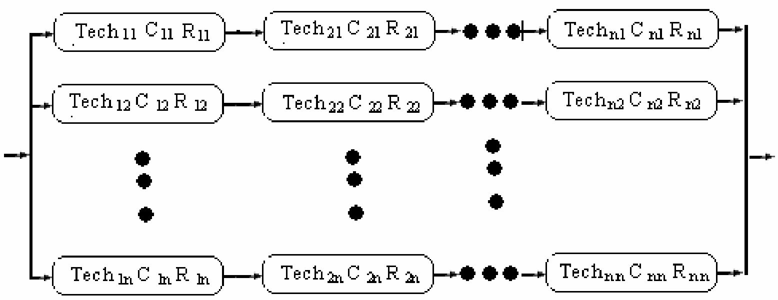

FIG.1. SERIES -PARALLEL POWER CELLS SYSTEMS

Every component of type $i = 1, ..., n$ contains a number of cells. All the cells of type i belonging to different technologies are connected in parallel. A multi-choice of cells and technologies will be adopted for each given system component. Each technology available in market has different costs, availabilities and nominal capacities. A vector of parameters $C_{i v_i}$, $R_{i v_i}$, $G_{i v_i}$ can be specified for each technology v of element of type i. The structure of system component i is defined by the numbers of parallel cells of each technology k_{iv} for $1 \le v \le V_i$ where V_i is the total number of technologies available of element of type i. The entire system structure is defined by a vector $k_i = \{k_{iv_i}\}$ $(1 \le i \le n, 1 \le v \le V_i)$ and the total cost of the system for given set $k_1, k_2, ..., k_n$ is formulated as follows:

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

Usually in electrical power energy, the loss of load probability index (LOLP) is used for reliability estimation [5]. This index measure the probability that the load demand will not be meet. Generally the load demand is represented by discrete random curve. If the time period of load is the set of M intervals, with duration T_j $(j = 1,...,M)$, and each demand level d_j has T_j duration, the LOLP is calculated as follows:

$$LOLP = \frac{1}{\sum_{j=1}^{M} T_j} \sum_{j=1}^{M} P(G_s < d_j)\ T_j \quad (2)$$

where $P(G_s < d_j)$ represents the probability that the total system capacity G_s is lower than the demand level d_j. All capacities production and demand are defined as a percentage of their total nominal value. The cumulative load curve is represented by vectors $d = \{d_i\}$ and $T = \{T_j\}$ who is known for every power system.

The measure of reliability system is defined by R index in reference [2], given by the expression $R = 1 - LOLP$. This index will be compared and must be not less than some preliminarily specified level R_0.

The problem of power system reliability optimization can be formulated as follow: find the system configuration $k_1, k_2, ..., k_n$ that provides the minimum total cost under reliability constraint. This problem can be started as below:

$$\text{Minimise} \quad C = \sum_{i=1}^{n} \sum_{v=1}^{V_i} k_{iv} C_{iv}$$

$$\text{Subject to} \quad R(d, t, k_1, k_2, ..., k_n) \ge R_0$$

3 RELIABILITY ESTIMATION METHOD

3.1. Principle of the method

The problem defined above is one of combinatorial optimization problem, it is necessary to enumerate a huge number of possible system states. Thus, it is required to use an effective and fast procedure for structure reliability estimation. As shown above, the main problem is to evaluate the index R for arbitrary series-parallel system. The probability that the total capacity of the power system is not less than a specific load demand level d must be calculated as:

$$R(d) = P\{G_s \ge d\} = 1 - P\{G_s < d\} \quad (3)$$

The procedure used to estimate this index is based on a modern mathematical technique: the UGF (or u-transform) technique in [9] [10] [11]. This method was first applied to real power system reliability assessment and optimization in [12] [13], and represent an extension of ordinary moment generating function [14]. The UGF, in our case, of a discrete variable G is defined as a polynomial

$$u(z) = \sum_{j=1}^{J} P_j z^{g_j} \tag{4}$$

where the discrete random variable G has J possible values, and P_j is the probability that G is equal to e_j. Under considerations if only the cells with total failures are considered. For instance for each element for system of type i and technology v has availability $R_{i v_i}$ and nominal capacity $G_{i v_i}$, then we denote by:

$P(G = G_s) = R_{iv}$ and $P(G = 0) = 1 - R_{iv}$. The UGF can be defined of such an element has only two terms as:

$$u_{iv} = (1 - R_{iv}) z^0 + R_{iv} z^{G_{iv}} \tag{5}$$

In the general case, failures may cause reduction of element capacities and, therefore, different capacity degradation, a multi-states (MSS) system performance should be considered. For MSS which has a finite number of states, we denote by H different levels of output performance system at each time t where $G(t) \in G = \{G_h, 1 \le h \le \text{H}\}$, and the system output performance can be defined by two finite vectors: E and $p = \{p_h(t)\} = \Pr\{G(t) = G_h\} \quad 1 \le h \le H$. In this case, the UGF, represented by the polynomial $u(z)$ can define all the MSS output performance, i.e. it represents all the possible states of the system by relating the probabilities of each state p_h to performance G_h of MSS in that state, and take the following form:

$$u_{MSS}(t, z) = \sum_{h=1}^{\text{H}} p_h(t) z^{G_h} \tag{6}$$

Having the MSS output performance, the system availability for arbitrary time t and demand d can be obtained using the following operator Ω_A

$$\begin{aligned} R(t,d) &= \Omega_A(u_{MSS}(t,z), d) \\ &= \Omega_A\Big(\sum_{h=1}^{\text{H}} p_h(t) z^{G_h}, d\Big) \\ &= \sum_{h=1}^{\text{H}} p_h(t)\, \alpha(G_h - d) \end{aligned} \tag{7}$$

where $\alpha(x) = \begin{cases} 1, & x \ge 0 \\ 0, & x < 0 \end{cases}$

after enough time has passed the probability become constant, and the MSS availability index denotes R is the function of requires demand d, it may be defined as

$$R(d) = \sum_{G_h \ge d} p_h \tag{8}$$

More explicitly, the probability that the total capacity of the power system is not less then a specified load level demand can be written as fellows:

$$P\{G \geq d\} = \Omega(u(z)z^{-d}) \tag{9}$$

where Ω is a distributive operator defined by the following expression:

$$\Omega(pz^{g-d}) = \begin{cases} p, & if \quad g \geq d \\ 0, & if \quad g < d \end{cases}$$

and

$$\Omega(\sum_{j=1}^{J} pz^{g_j - d}) = \sum_{j=1}^{J} \Omega(pz^{g_j - d}) \tag{10}$$

3.2. Series-parallel structure

For power system component containing n cells connected in different ways, in parallel case, the total capacity is equal to the sum of capacities of all its cells. There fore, the u-function can be calculated by using the Γ operator:

$$u_s(z) = \Gamma(u_1(z),...,u_n(z)) = \prod_{i=1}^{n} u_i(z)$$

where

$\Gamma(e_1,...,e_n) = \sum_{i=1}^{n} e_i$ so that

$$\begin{aligned}\Gamma(u_1(z),u_2(z)) &= \Gamma(\sum_{i=1}^{n} p_i z^{a_i}, \sum_{j=1}^{m} q_j z^{b_j}) \\ &= \sum_{i=1}^{n}\sum_{j=1}^{m} p_i q_j z^{a_i + b_j}\end{aligned} \tag{11}$$

4 ILLUSTRATIVE EXAMPLE

In order to illustrate the proposed method (ant colony algorithm), a numerical example is solved by use of the data given in table 1. Each power cells of the subsystem is considered as a unit with total failures. Table 2 contains the data of cumulative battery demand. The maximum numbers of cells put in parallel series are set to (4,5,4). The number of ants used to find the best solution is 100. The simulation results depend greatly on the values of the coefficients α and β. Several simulations are made for α=5 and β=1 and the best solution is obtained in 400 cycles. Table 3 presents the best solution obtained.

4.1. Description of the system to be optimized

The sun electrical power generated by cells system which supplies the consumers loading batteries is designed with 03 basic subsystems as depicted in figure.1. The process of sun electrical power cells system distribution follows as: The electrical power is generated from the sun by parallel series cells units. Then stored in batteries in DC current

The series parallel systems topologies depend strongly by the space constraint. Fig.2 illustrates the system to be optimized coupled with the battery loading.

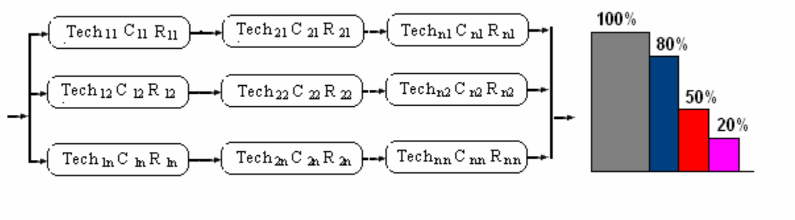

FIG.2. SERIES -PARALLEL POWER CELLS SYSTEMS COUPLED WITH DEMAND CURVE

The characteristics of the products available on the market for each type of device are presented in table 1. This table shown for each subsystem availability *A*, nominal capacity *G* and cost per unit *C*. With out loss of generality both the component capacity and the demand levels table 2 can be measured as a percentage of the maximum capacity.

TABLE 1. DATA OF DIFFERENT TECHNOLOGIES

Components #	**Technologies of Cells #**	**Availability R**	**Cost *C***	**Capacity G**
	1	0.980	0.590	120
	2	0.977	0.535	100
1	3	0.982	0.470	85
	4	0.978	0.420	85
	1	0.995	0.205	100
	2	0.996	0.189	92
2	3	0.997	0.091	53
	4	0.997	0.056	28
	5	0.998	0.042	21
	1	0.971	7.525	100
	2	0.973	4.720	60
3	3	0.971	3.590	40
	4	0.976	2.420	20

TABLE 2. PARAMETERS OF THE CUMULATIVE BATTERY DEMAND CURVE

Loading level (%)	**100**	**80**	**50**	**20**
Duration (h)	4203	788	1228	2536
Probability	0.479	0.089	0.140	0.289

TABLE3. OPTIMAL SOLUTIONS OBTAINED BY ANT COLONY ALGORITHM

$\mathbf{R_0}$	Optimal Structure	Computed Availability **R**	Computed Cost **C (ml$)**
0.975	Subsystem **1: Cells 1(5)- 6(3)** Subsystem **2: Cells 1(4) – 3(5)** Subsystem **3: Cells 1(1)- 3(4)** Subsystem **4: Cells 3(9)- 1(5) –1(6)-1(7)-2(8)** Subsystem **5: Cells 1(3) – 3(4)**	**0.978**	**04.88**

4.2 Optimization Result And Discussion

Table 3 shows the best optimal power cells structure obtained by the suggested ant colony for one desired reliability levels A_0 (0.975). This letter illustrate the computed cost and availability index to the corresponding cells structure. In the ant algorithm a set of parameter values are tested. When the demand varies the best values corresponding to the merit structures are: $\alpha = 5$, $\beta = 1$, $\tau_0 = 0.5$ and $\rho = 0.080$. The choice of these values affects strongly the solution. Since it is a heuristic method only near optimal solutions can be obtained.

To compare this meta-heuristic to the combinatorial one, the space searching is about 100*400 cycles, but in combinatorial one is 10^{48}. The Program was run on PC Intel.**IV** with **2.4** GHz. The time to find the best solution is 1'.05". Not realistic in combinatorial method.

5 CONCLUSION

In this paper, we solve the power cells optimal structure which is a very interesting problem often reencountered in energy industry or manufacturing industry. It is formulated as redundancy optimization problem. The resolution of this problem use a developing ant colony method. This new algorithm for choosing an optimal series-parallel power cells structure configuration is proposed which minimizes total investment cost subject to availability constraints. This algorithm seeks and selects cells technologies among a list of available products according to their availability, nominal capacity (performance) and cost. Also defines the number and the kind of series-parallel power cells to put in each subsystem when consumers' demand changes. The proposed method allows a practical way to solve wide instances of reliability optimization problem of multi-state systems without limitation on the diversity of cells technologies put in series-parallel. A combination is used in this algorithm based on the universal moment generating function and an ACO algorithm.

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