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Mathematical modelling and performance optimization of CO_2 cooling system of a fertilizer plant

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A B S T R A C T

This paper discusses the mathematical modeling and performance optimization of CO_2 cooling system of a fertilizer plant using genetic algorithm. The fertilizer plant comprises of various systems viz. shell gasification and carbon recovery, desulphurization, co-shift conversion, decarbonation- CO_2 cooling, CO_2 removal, nitrogen wash and ammonia synthesis, etc. One of the most important functionaries of a fertilizer plant is CO_2 cooling system. The CO_2 cooling system of a fertilizer plant has five main subsystems, arranged in series. We propose a mathematical model, which considers exponential distribution for the probable failures and repairs. We also use probabilistic approach and derive differential equations based on Markov birth-death process. These equations are then solved using normalizing conditions to determine the steady state availability of the CO_2 cooling system. The performance of each subsystem of CO_2 cooling system of a fertilizer plant is also optimized using genetic algorithm. The results of the proposed model of this paper is useful to the plant management for the timely execution of proper maintenance decisions and hence to enhance the system performance.

1. Introduction

There are two ways of increasing availability of an engineering system: First by increasing the availability of each component and second, by using redundant components. Availability of a component can be increased by improving reliability and maintainability. If reliability is increased, the system can work for longer periods of time; if the maintenance program is improved, the system can be repaired quickly. Reliability is the probability that a system or component will perform its design function successfully at an interval of time [0,t]. The reliability function can easily be obtained by failure time analysis of components or systems, and is complementary to the cumulative distribution function of failure times. High system reliability is desirable to reduce overall costs of production and risk of hazards for the complex and sophisticated plants based on advanced technology such as fertilizer, thermal, paper, sugar etc. The fertilizer plant, one of such systems, consists of shell gasification and carbon recovery, desulphurization, co-shift conversion, CO_2 cooling, CO_2 removal, nitrogen wash and ammonia synthesis, etc. Considerable efforts have been made by the

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researchers/engineers to provide efficient and reliable operation of fertilizer plant. Present work is an attempt in this direction to keep such systems in upstate for long time by improving the overall reliability of the CO_2 cooling system of particular fertilizer plant to maintain system in failure free state as much as possible. The CO_2 cooling system is an important functionary of the fertilizer plant, which consists of five subsystems: A, B, C, D, and E with one standby subsystem in each C, D, and E arranged in series. However, during operation they are liable to fail in a random fashion. The failed elements can however be inducted back into service after repairs/replacements. The rate of failure of the components in the system depends on the operating conditions and repair policy used. The aim of this paper is to present a procedure with an adaptation of an optimization technique. Availability has a wider scope than reliability, as it takes into account maintenance time analysis in addition to failure time analysis. The procedure is based on genetic algorithm (GA), which is suitable for problems with this degree of complexity. A GA is a search strategy that employs random choice to guide a highly exploitative search, striking a balance between exploration of the feasible domain and exploitation of 'good' solutions. This strategy is analogous to biological evolution. Different to the classic optimization algorithms, the GA does not work with only one point in the search space, but with a group of points, simultaneously. The number of points is previously determined by a parameter known as population size. The GA does not need to use differential calculus. It can be considered a robust method, because it is not influenced by local maximum or minimum, discontinuity or noise in the objective function. GA operators are the instruments used by the algorithm to reach the optimum point of the function. Four operators, described by Goldberg (2003), were developed in the computer program: mutation, crossover, population size and generation size. This paper discusses performance optimization of CO_2 cooling system in a medium sized fertilizer plant by using genetic algorithm.

2. Literature review

The available literature reflects that several approaches have been used to analyze the steady state behaviour of various systems. Somani and Ritcey (1992) presented reliability analysis for systems with variable configuration. Dhillon and Singh (1981) and Srinath (1994) have frequently used the Markovian approach for the availability analysis, using exponential distribution for failure and repair times. Kurien (1988) developed a predictive model for analyzing the reliability and availability of an aircraft training facility. The model was useful for evaluating various maintenance alternatives. Kenaraagui and Husseyni (1988) dealt with reliability and availability optimization of fusion power plants. Boudali and Dugan (2005) discussed discrete-time Bayesian network reliability modeling and analysis framework. Arora and Kumar (1997) discussed availability analysis of steam and power generation systems in thermal power plant Kumar et al. (1988, 1993) dealt with reliability, availability and operational behavior analysis for different systems in the paper plant. Kumar et al. (1999) dealt with maintenance management for Ammonia Synthesis System in fertilizer plant. Tewari et al. (2000, 2005) dealt with the determination of availability for the systems with elements exhibiting independent failures and repairs or the operation with standby elements for sugar industry. He also dealt with mathematical modeling and behavioral analysis for a refining system of a sugar industry using GA. Sanjeev et al. (2008, 2009, 2010) dealt with simulation model for evaluating the performance of urea decomposition system in a fertilizer plant. Tsai et al. (2001) discussed the optimizing preventive maintenance for mechanical components using genetic algorithms. Goldberg (2003) described GA operators used by the algorithm to reach the optimum point of the function. Chales and Kondo (2003) tackled a multiobjective combinatorial optimization problem. They used GA to optimize the availability and cost of a series and parallel repairable system. Castro and Cavalca (2003) presented an availability optimization problem of an engineering system assembled in series configuration which has the redundancy of units and teams of maintainance as optimization parameters. GA was used to reach the objective of availability, considering installation and maintenance costs.

3. CO_2 cooling system description

In this process the gas mixture from co conversion system enters the heat exchanger and then ammonia chiller in which it gets cooled to -16^{0}C and -25^{0}C, respectively. Then this gas enters CO_2 absorber subsystem where lean methanol is sprayed from the top and CO_2 is absorbed. The gas mixture free from CO_2 rises up in the absorber and collected in tank, from where it is purified using nitrogen wash.

The CO_2 cooling system consists of five subsystems, which are as follows:

(1) Subsystem (A): Consists of separators, heat exchanger and ammonia chiller in series. Failure of any unit will cause complete failure of the system.

(2) Subsystem (B): Consists of CO_2 absorber and CO_2 separator in series. Failure of any unit will cause complete failure of the system.

(3) Subsystem (C): This subsystem consists of two CO_2 absorber methanol pumps; one working at a time and other remains standby. The system failure occurs only when both pumps fail, simultaneously.

(4) Subsystem (D): This subsystem consists of two lean methanol high pressure pumps, one working at a time and the other remains standby. The system failure occurs only when both pumps fail, simultaneously.

(5) Subsystem (E): This subsystem consists of two CO_2 absorber circulation pumps; one working at a time and the other remains standby. The system failure occurs only when both pumps fail, simultaneously.

4. Assumptions and notations

The transition diagram (Fig. 1) of the CO_2 cooling system shows the two states, the system can acquire i.e. full working and failed state. Based on the transition diagram, a performance-evaluating model has been developed. The following assumptions and notations are addressed in developing the probabilistic models for the CO_2 cooling system of the fertilizer plant concerned:

4.1. Assumptions

1. Failure/repair rates are constant over time and statistically independent.

2. A repaired unit is as good as new, performance wise, for a specified duration.

3. Sufficient repair facilities are provided.

4. Standby units are of the same nature as that of active units.

5. System failure and repair follows the exponential distribution.

6. Service includes repair and/or replacement.

7. System may work at reduced capacity.

8. There are no simultaneous failures.

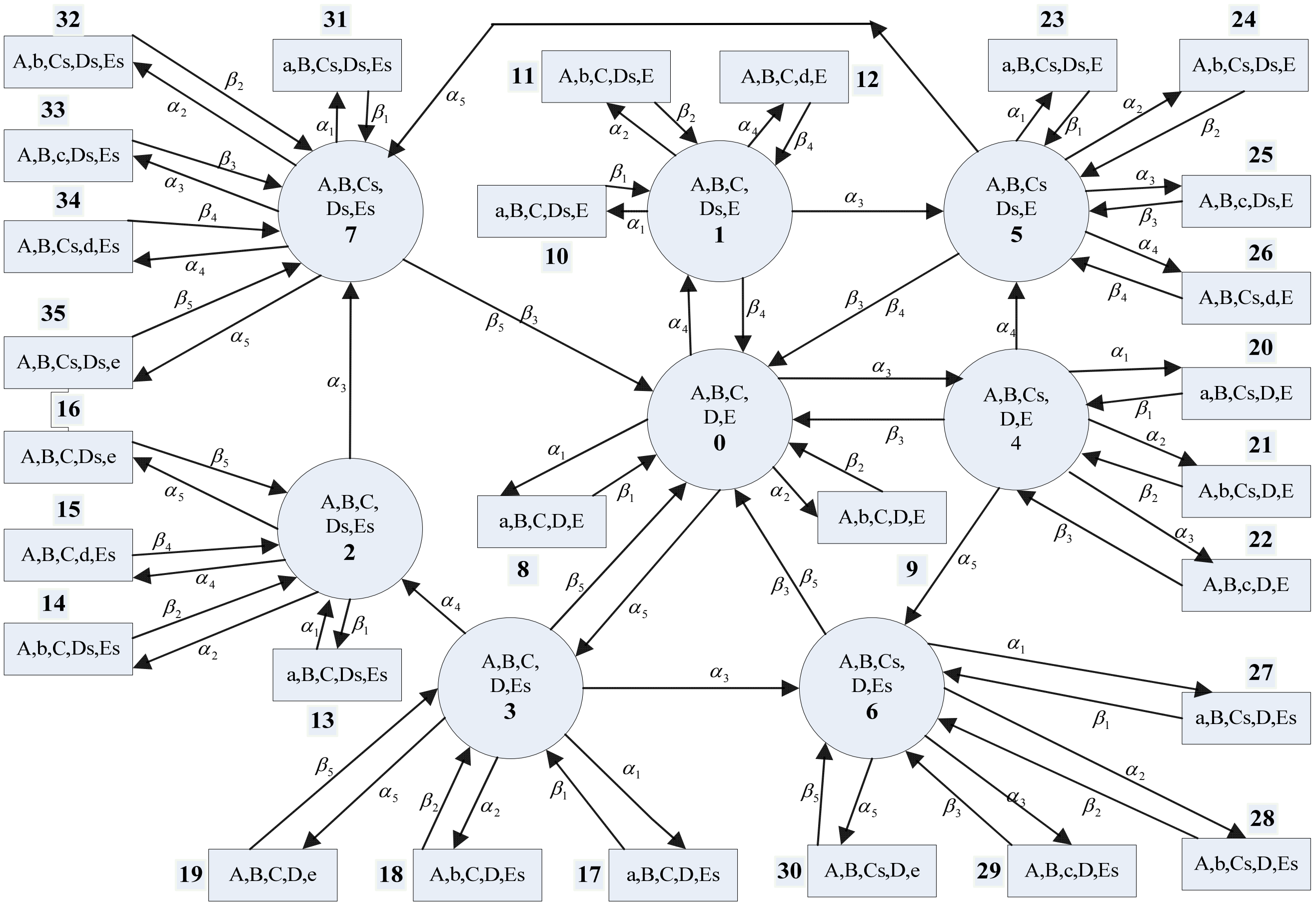

Fig. 1. Transition diagram of CO_2 cooling system of fertilizer plant

4.2. Notations

A, B, C, D, E	denotes that the subsystems are in full operating state.
Cs, Ds, Es	denotes that the subsystems C, D and E are working on standby unit.
a, b, c, d, e	denotes that the subsystems are in failed state.
$P_0(t)$	Probability that at time t all subsystems are in original working state (without standby unit).
$P_i(t)$	Probability that at time t all subsystems are in full load condition (standby mode) for i = 1, …,7.
$P_j(t)$	Probability that at time t all subsystems are in breakdown state for j = 8, …, 35.
α_i, i =1- 5	mean failure rates in A, B, C, D, E
β_i, i =1- 5	mean rate of repairs in A, B, C, D, E
Δt	time increment
d/dt	derivative with respect to ‘t’
○	system working at full load condition
▭	system breakdown

5. Mathematical modeling of CO_2 cooling system

Mathematical modeling has been developed for the prediction of steady state availability of the individual components as well as entire system. The failure and repair rates of different subsystems, available from the maintenance sheets of the fertilizer plant, are used as standard input information for the analysis (Kumar et al., 1988; Sunand, 1999). The state of the system defines the condition at any instant of time and the information is useful in analyzing the current state and in the prediction of the failure state of the system. If the state of the system is probability based, then the model is a Markov probability model. Markov model is defined by a set of probabilities P_{ij}, where P_{ij} is the probability of transition from any state *i* to any state *j*. One of the most important features of the Markov process is that the transition probability P_{ij}; depends only on states *i* and *j* and is completely independent of all past states except the last one, state *i*.

Let the probability of *n* occurrences in time *t* be denoted by $P_n(t)$, i.e.,

Probability(X = n, t) = $P_n(t)$ (n = 0, 1, 2 . . .).

Then, $P_0(t)$ represents the probability of zero occurrences in time *t*. The probability of zero occurrences in time (t + Δt) is given by Eq. (1); i.e.

$$P_0(t+\Delta t) = (1-\alpha\,\Delta t).P_0(t) + (\beta\,\Delta t)P_1(t)\,. \tag{1}$$

Similarly

$$P_1(t+\Delta t) = (\alpha.\Delta t).P_0(t) + (1-\beta.\Delta t).P_1(t). \tag{2}$$

The Eq. (2) shows the probability of one occurrence in time (t + Δt) and is composed of two parts, namely, (a) probability of zero occurrences in time *t* multiplied by the probability of one occurrence in the interval Δt and (b) the probability of one occurrence in time *t* multiplied by the probability of no occurrences in the interval Δt. Then simplifying and putting $\Delta t \to 0$ yields,

$$(\frac{d}{dt} + \alpha)P_0(t) = \beta\,P_1(t)\,. \tag{3}$$

Using the concept used in Eq. (3) and various probability considerations, the following differential equations associated with the transition diagram of CO_2 cooling system are formed

$$P_o(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i\right]=\sum_{i=4}^{7}P_i(t).\beta_3+\{P_2+P_3+P_6+P_7\}(t).\beta_5+\{P_1+P_5+P_2\}(t).\beta_4+\beta_2P_9(t)+\beta_1P_8(t), \tag{4}$$

$$P_1(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i\right] = P_0(t)\alpha_4 + \beta_4P_{12}(t) + \sum_{i=1}^{2}\beta_iP_{i+9}(t), \tag{5}$$

$$P_2(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+\beta_5+\beta_4\right] = P_3(t)\alpha_4 + \alpha_5P_1(t) + \sum_{i=1}^{2}\beta_iP_{i+12}(t) + \sum_{i=4}^{5}\beta_iP_{i+11}(t), \tag{6}$$

$$P_3(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+\beta_5\right] = \alpha_5P_0(t) + \beta_5P_{19}(t) + \sum_{i=1}^{2}\beta_iP_{i+16}(t), \tag{7}$$

$$P_4(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+\beta_3\right] = \alpha_3P_0(t) + \sum_{i=1}^{3}\beta_iP_{i+19}(t), \tag{8}$$

$$P_5(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+\beta_3+\beta_4\right]=\alpha_4P_4(t)+\alpha_3P_1(t)+\sum_{i=1}^{4}\beta_iP_{i+22}(t), \tag{9}$$

$$P_6(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+2\alpha_5+\beta_3+\beta_5\right]=\alpha_5P_4(t)+\alpha_3P_3(t)+\beta_5P_{30}(t)+\sum_{i=1}^{3}\beta_iP_{i+26}(t), \tag{10}$$

$$P_7(t)\left[\frac{d}{dt}+\sum_{i=1}^{5}\alpha_i+\beta_3+\beta_5\right]=\alpha_5P_5(t)+\alpha_3P_2(t)+\sum_{i=1}^{5}\beta_iP_{i+30}(t), \tag{11}$$

$$P_i(t)\left[\frac{d}{dt}+\beta_m\right]=P_k(t).\alpha_m. \tag{12}$$

With the initial condition P_0 (0) =1 and 0, otherwise. The various subsystems of a fertilizer plant are expected to run failure free for a long duration of time (steady state conditions). The steady state availability of each subsystem is obtained by putting d/dt = 0 at $t \to \infty$ into respective differential equations.

$$P_i\beta_m = P_k.\alpha_m,\ P_i = (\alpha_m/\beta_m)P_k \tag{13}$$

where

m = 1: i = 8, 10, 13, 17, 20, 23, 27, 31, k = 0, 1, 2, 3, 4, 5, 6, 7;

m = 2: i = 9, 11, 14, 18, 21, 24, 28, 32, k = 0, 1, 2, 3, 4, 5, 6, 7;

m = 3: i = 22, 25, 29, 33, k = 4, 5, 6, 7;

m = 4: i =12, 15, 26, 34, k = 1, 2, 5, 7;

m = 5: i =16, 19, 30, 35, k = 2, 3, 6, 7.

5.1. Solutions of Equations

Solving these equations recursively yields all values of P in terms of P_0.

$$P_1 = (\alpha_4/C_2)P_0, \tag{14}$$

$$P_2 = C_{10}P_0, \tag{15}$$

$$P_3 = (\alpha_5/C_4)P_0, \tag{16}$$

$$P_4 = (\alpha_3/C_5)P_0, \tag{17}$$

$$P_5 = C_{13}P_0, \tag{18}$$

$$P_6 = C_{14}P_0, \tag{19}$$

$$P_7 = C_{15}P_0, \tag{20}$$

$C_1=\alpha_4+\alpha_3+\alpha_5$, $C_2=\beta_4+\alpha_3+\alpha_5$, $C_3=\beta_4+\alpha_3+\beta_5$, $C_4=\alpha_4+\alpha_3+\beta_5$, $C_5=\alpha_4+\beta_3+\alpha_5$,

$$C_6 = \alpha_5 + \beta_3 + \beta_4 , C_7 = \alpha_5 + \beta_3 + \beta_5 , C_8 = \beta_3 + \beta_5 , C_{10} = \frac{\alpha_5\alpha_4(C_2 + C_4)}{C_3C_4C_2}, \; C_{13} = \frac{\alpha_3\alpha_4(C_2 + C_5)}{C_6C_5C_2},$$

$$C_{14} = \frac{\alpha_5\alpha_3(C_5 + C_4)}{C_7C_4C_5}, C_{15} = \left(\frac{\alpha_5\alpha_4\alpha_3}{C_8}\right)\left\{\left(\frac{(C_2 + C_4)}{C_3C_4C_2}\right) + \left(\frac{(C_2 + C_5)}{C_6C_5C_2}\right)\right\}.$$

The probability of full working capacity, namely, P_0 is determined by using normalizing condition: (i.e. sum of the probabilities of all working states, reduced capacity and failed states is equal to 1):

$$\sum_{i=0}^{35} P_i = 1, \quad \text{Hence} \quad P_0 = 1/N$$

where

$$N = \left(1 + \frac{\alpha_4}{C_2} + C_{10} + \frac{\alpha_5}{C_4} + \frac{\alpha_3}{C_5} + C_{13} + C_{14} + C_{15}\right)\left(1 + \frac{\alpha_1}{\beta_1} + \frac{\alpha_2}{\beta_2}\right) + \left(C_{10} + C_{15}\right)\left(\frac{\alpha_4}{\beta_4} + \frac{\alpha_5}{\beta_5}\right) + \frac{\alpha_5}{\beta_5}\left(\frac{\alpha_5}{C_4} + C_{14}\right) + \frac{\alpha_3}{\beta_3}\left(\frac{\alpha_3}{C_5} + C_{13} + C_{14} + C_{15}\right) + \frac{\alpha_4}{\beta_4}C_{13}.$$

$\therefore$ Steady state availability (Av.) of system is given by summation of all working states probabilities $\sum_{i=0}^{7} P_i$

$$Av. = P_0 + P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7,$$

$$Av. = \frac{1}{N}\left[1 + \frac{\alpha_4}{C_2} + \frac{\alpha_5}{C_4} + \frac{\alpha_3}{C_5} + \left(\frac{\alpha_4\alpha_5}{C_2}\left(\frac{C_4 + C_2}{C_3C_4} + \frac{C_5 + C_2}{C_5C_6}\right)\right)\left(1 + \frac{\alpha_3}{C_8}\right) + \frac{\alpha_3\alpha_5\left(C_5 + C_4\right)}{C_4C_5C_7}\right].$$

Therefore, the availability of the system (Av.) represents the performance model of CO_2 cooling system of fertilizer plant.

6. Genetic algorithm technique

The genetic algorithm (GA) (Goldberg, 2003) is a search method based on the concepts of biological evolution and reproduction. Previous works indicate that a GA is recommended for problems involving complex mathematical expressions in their modeling. An important advantage is that it does not require the use of differential calculus. The GA is a model of machine learning, which derives it's behavior from a metaphor of some of the mechanisms of the evolution in the nature (Tsai, 2001). The implementation of GA for a particular problem must have the following components,

1) Genetic representation for potential solutions to the problem,
2) Way to create an initial population of potential solutions,
3) Evaluation function that plays the role of the environmental rating solutions in terms of their "fitness". This is because the population undergoes a simulated evolution at each generation .This role of an environment helps relatively "good" solutions to reproduce while relatively "bad" solutions die.
4) Genetic operators then alter the composition of children. The multidirectional search is performed by maintaining a population of potential solutions and encourages the information exchange among these directions.

5) Values for various control parameters that the GA uses (population size, probabilities of applying Genetic algorithm etc.)

With the above necessities, the action of GA for parameter optimization problem can be stated.

7. Performance optimization using GA

Different to the classic optimization algorithms, the GA does not work with only one point in the search space, but with a group of points, simultaneously. The number of points is previously determined by a parameter known as population size. The GA does not need to use differential calculus. It can be considered a robust method, because it is not influenced by local maximum or minimum, discontinuity or noise in the objective function. GA operators are the instruments used by the algorithm to reach the optimum point of the function. Four operators, described by Goldberg (2003), were developed in the computer program: mutation, crossover, inversion and selection. The performance behaviour of CO_2 cooling system is highly influenced by the failure and repair parameters of each subsystem. These parameters ensure high performance of the CO_2 cooling system. The proposed GA of this paper coordinates the failure and repair parameters of each subsystem for stable system performance, i.e. high availability. Here, the number of parameters is ten (five failure parameters and five repair parameters). The design procedure is described as follows (Tsai, 2001; Charles, 2003):

To use GA for solving the given problem, the chromosomes are to be coded in real structures. Here, concatenated, multi-parameter, mapped, fixed point coding is used. Unlike, unsigned fixed point integer coding parameters are mapped to a specified interval [X_{min}, X_{max}], where X_{min} and X_{max} are the maximum and the minimum values of system parameters, respectively . The maximum value of the availability function corresponds to optimum values of system parameters. These parameters are optimized according to the performance index i.e. desired availability level. To test the proposed method, failure and repair rates are determined simultaneously for the optimal value of system availability. Effects of population size and the number of generations on the availability of CO_2 cooling system are shown in Table 1 and 2. To specify the computed simulation more precisely, trial sets are also chosen for genetic algorithm and system parameters. The performance (availability) of CO_2 cooling system is determined by using the designed values of the system parameters.

Failure and repair rate parameter constraints

$$(\alpha_1, \beta_1, \quad \alpha_2, \beta_2, \quad \alpha_3, \beta_3, \quad \alpha_4, \beta_4, \quad \alpha_5, \beta_5)$$

$$\alpha_1 \in [0.002, 0.008] \; \alpha_2 \in [0.002, 0.008] \quad \alpha_3 \in [0.02, 0.1] \quad \alpha_4 \in [0.1, 0.9] \quad \alpha_5 \in [0.02, 0.08]$$

$$\beta_1 \in [0.02, 0.05] \quad \beta_2 \in [0.02, 0.05] \quad \beta_3 \in [0.3, 0.9] \quad \beta_4 \in [0.3, 0.9] \quad \beta_5 \in [0.2, 0.5]$$

Here, real-coded structures are used.

Maximum number of population size is varied from 20 to 160. Also the number of generations, crossover probability, mutation probability and total number of run are set to 100, 0.8, 0.1 and 01, respectively.

The optimum value of system's performance is 91.98 %, for which the best possible combination of failure and repair rates is α_1 = 0.0022, β_1 = 0.0498, α_2 = 0.0020, β_2 = 0.0499, α_3 = 0.0205, β_3 = 0.8946, α_4 = 0.1226, β_4 = 0.8563, α_5 = 0.0204, β_5 = 0.4926, at population size 160, as given in Table 1. The maximum number of generations is varied from 50 to 300. Also the population size, crossover and mutation probability and total number of run are 100, 0.8, 0.1 and 01, respectively. The effect of population size on availability of the CO_2 cooling system is shown in Fig. 2.

Table 1
Effect of population size on availability of CO_2 cooling system

Pop. Size	Av.	α_1	α_2	α_3	α_4	α_5	β_1	β_2	β_3	β_4	β_5
20	0.8904	0.0021	0.0034	0.0351	0.1433	0.0233	0.0494	0.0461	0.7985	0.8185	0.4162
40	0.9123	0.0023	0.0020	0.0357	0.1548	0.0202	0.0464	0.0491	0.8472	0.8470	0.4842
60	0.9151	0.0022	0.0021	0.0248	0.1014	0.0243	0.0484	0.0490	0.8674	0.8996	0.4925
80	0.9056	0.0022	0.0025	0.0200	0.1537	0.0268	0.0476	0.0478	0.8755	0.8998	0.4852
100	0.9168	0.0022	0.0021	0.0265	0.1023	0.0205	0.0495	0.0497	0.8752	0.8885	0.4911
120	0.9070	0.0023	0.0025	0.0208	0.1997	0.0212	0.0487	0.0494	0.8827	0.8427	0.4936
140	0.9141	0.0022	0.0022	0.0207	0.1051	0.0204	0.0488	0.0474	0.8826	0.8983	0.4879
160	**0.9198**	**0.0022**	**0.0020**	**0.0205**	**0.1226**	**0.0204**	**0.0498**	**0.0499**	**0.8946**	**0.8563**	**0.4926**

Table 2
Effect of number of generation on availability of CO_2 cooling system

Gen. Size	**Av.**	α_1	α_2	α_3	α_4	α_5	β_1	β_2	β_3	β_4	β_5
25	0.9160	0.0020	0.0021	0.0331	0.1608	0.0230	0.0484	0.0475	0.8164	0.8537	0.4517
100	0.9168	0.0022	0.0021	0.0265	0.1023	0.0205	0.0495	0.0497	0.8752	0.8885	0.4911
175	0.9195	0.0020	0.0020	0.0205	0.1019	0.0206	0.0499	0.0464	0.8928	0.8813	0.4623
225	**0.9206**	**0.0021**	**0.0020**	**0.0219**	**0.1108**	**0.0211**	**0.0492**	**0.0489**	**0.8782**	**0.8987**	**0.4990**
250	0.9175	0.0020	0.0022	0.0204	0.1007	0.0205	0.0499	0.0484	0.8994	0.8811	0.4978
300	0.9148	0.0021	0.0023	0.0204	0.1047	0.0206	0.0498	0.0493	0.8773	0.8962	0.4988

The optimum value of system's performance is 92.06 %, for which the best possible combination of failure and repair rates is α_1 = 0.0021, β_1 = 0.0492, α_2 = 0.0020, β_2 = 0.0489, α_3 = 0.0219, β_3 = 0.8782, α_4 = 0.1108, β_4 = 0.8987, α_5 = 0.0211, β_5 = 0.4990 at generation size 225, as given in Table 2. The effect of number of generations on availability of the CO_2 cooling system is also shown in Fig. 3.

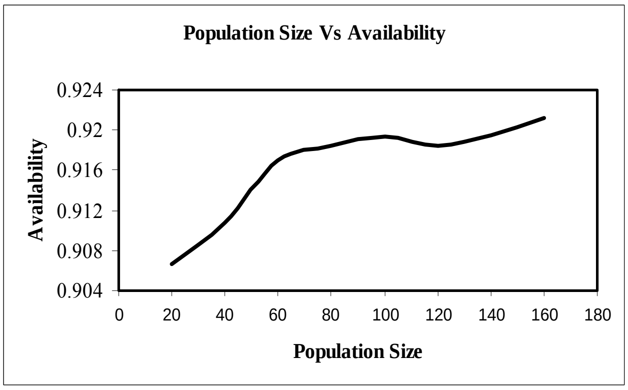

Fig. 2. Effect of population size on availability of CO_2 cooling system

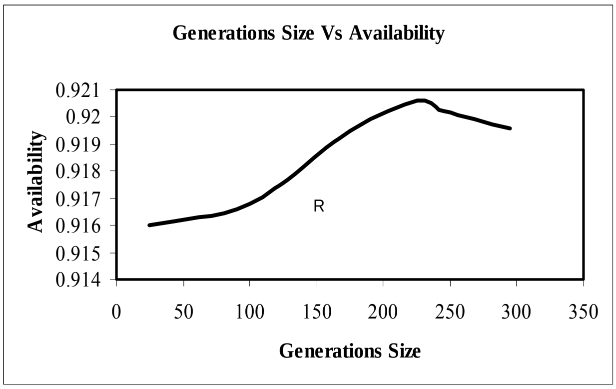

Fig. 3. Effect of number of generations on availability of CO_2 cooling system

8. Conclusions

The performance optimization of the CO_2 cooling system of a fertilizer plant has been discussed in this paper. GA technique has been proposed to select the various feasible values of the system failure and repair parameters. The proposed GA could efficiently solve a complex perfromance optimization of the CO_2 cooling system of a fertilizer plant studied in this paper. The proposed GA helps to determine the optimum number of redundant components and maintenance resources.

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References

Arora, N., & Kumar, D. (1997). Availability analysis of steam and power generation systems in thermal power plant. *International Journal of Microelectronics Reliability,* 37, 795-799.

Boudali, H., & Dugan, J. B. (2005). A discrete-time Bayesian network reliability modeling and analysis framework. *Reliability Engineering and System Safety***,** 87, 337–349.

Castro, H. F., & Cavalca, K. (2003). Availability optimization with genetic algorithm. *International Journal of Quality and Reliability Management*, 20 (7), 847-863.

Chales, C., & Kondo, A. (2003). Availability allocation to repairable systems with genetic algorithms: a multi-objective formulation. *Reliability Engineering and System Safety,* 82 (3), 319-330.

Dhillon, B.S., & Singh, C. (1981). *Engineering reliability- new techniques and applications.* New York: John Wiley and Sons.

Goldberg, D. E. (2003). *Genetic algorithm in search, optimization and machine learning*. Pearson Education Asia New Delhi.

Kurien, K. C. (1988). Reliability and availability analysis of repairable system using discrete event simulation. Ph.D Thesis, Indian Institute of Technology, New Delhi,

Kenaraagui, R., & Husseiny, A. (1988). Reliability and availability analysis of fusion power plants. *International Journal of Engineering,* 1 (1), 63-72.

Kumar, D., Singh, I.P., & Singh, J. (1988). Reliability analysis of the feeding system in the paper industry. *International Journal of Microelectronics Reliability,* 28, 213-215.

Kumar, D., Singh, I.P., & Singh, J. (1988). Availability of the feeding system in the sugar industry. *International Journal of Microelectronics Reliability,* 28, 867-871.

Kumar D., & Pandey, P.C. (1993). Maintenance planning and resource allocation in urea fertilizer Plant. *International Journal of Quality and Reliability Engineering,* 9, 411-423.

Kumar, S., Kumar, D. & Mehta, N. P. (1999). Maintenance Management for Ammonia Synthesis System in a Urea Fertilizer Plant. *International Journal of Management and System (IJOMAS),* 15, 211-214.

Kumar, S., Tewari, P.C., & Kumar, S. (2008). Development of performance evaluating model for CO-Shift conversion system in the fertilizer plant. *International Journal of Engineering Research and Industrial Applications (IJERIA),* 1(6), 369-382.

Kumar, S., Tewari, P.C., & Kumar, S. (2009). Simulation model for evaluating the performance of urea decomposition system in a fertilizer plant. *International Journal of Industrial Engineering and Practices,*1(1),10-14.

Kumar, S., Tewari,P. C., Kuma, S. & Gupta, M. (2010). Availability optimization of CO-Shift conversion system of a fertilizer plant using genetic algorithm technique. *Bangladesh Journal of Scientific and Industrial Research (BJSIR),* 45 (2),133-140.

Somani, A. K., & Ritcey, J. A. (1992). Computationally efficient phased mission reliability analysis for systems with variable configuration., *IEEE Transactions on Reliability,* 41(4), 504–511.

Srinath, L. S. (1994). *Reliability Engineering*, 3rd. edition, East-West Press Pvt. Ltd., New Delhi.

Tewari, P.C., Kumar, D., & Mehta, N.P. (2000). Decision support system of refining system of sugar plant. *Journal of Institution of Engineers (India*), 84*,* 41-44.

Tewari, P.C., Joshi, D., & Rao, S. M., (2005). Mathematical modeling and behavioural analysis of a refining system using genetic algorithm. *Proceedings of National Conference on Competitive Manufacturing Technology and management for Global Marketing,* Chennai, 131-134.

Tsai, Y.T., Wang, K.S., & Teng, H.Y. (2001). Optimizing preventive maintenance for mechanical components using genetic algorithms. *Reliability Engineering and System Safety*, 74 (1), 89-97.