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Some Aspects About the Reliability Analysis of a Phased-Mission Geothermal Power Plant

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ABSTRACT

In fact the mission for a geothermal power plant consists of several phases. The system configuration, operational requirements for individual components, success criteria and stress on the components, can change from phase to phase. Furthermore, the duration of any phase can use deterministic or random models. All these changes and possibilities affect the system reliability. Thus, in this paper, I propose a tool which can assist in modelling and analyzing from this point of view a geothermal power plant system, and it also is computing the final reliability.

1. INTRODUCTION

When designing a system, several choices must be made concerning the type of components to be used and their assembly configuration. The choice is driven by the interaction of reliability/availability objectives with the economic costs associated to the design implementation, system construction and future operation, Marseguerra et al. (2000), Fyffe (1968), Goldberg (1989). Fault tolerant systems are often used in missions characterized by the existence of many phases during their mission. Often, a mission consists of several phases. The system configuration, operational requirements for individual components, success criteria and stress on the components (and thus the failure rates) can change from phase to phase. Furthermore, the duration of any phase can use deterministic or random models. All these changes and possibilities affect the system reliability. This paper describes a technique to analyze the geothermal plant multi-phased system efficiently. We address the issue of change, from phase to phase, in system configuration and in success criteria.

2. THE SYSTEM PRESENTATION

A good functioning of the power plant following the required thermodynamic cycle has to insure the heat transfer between the CO_2 and the geothermal water or the cold water. The control has to maintain constant the CO_2 pressure and temperature in all the important states of the thermodynamic cycle. Together with other specialists, we decided that we have to implement loops to control the following parameters: *t1* (CO_2 temperature after vaporization in the heat exchangers), *t3* (CO_2 temperature after the condensation in the heat exchanger), and *h* (level of the liquid CO_2 in the tank). Figure 1 shows the power plant layout, together with the control loops shown using dotted lines. The reliability of a system depends critically on its individual component reliability and how component are connected in the reliability scheme. To obtain a realistic reliability evaluation of a control system all levels in the system must be examined. For reliability purposes three levels are defined: component level, control loop level and finally the control system level. The reliability model of this structure is given in Fig. 2, Fig. 3, and Fig. 4.

At the design stage, analyses are to be performed in order to guide the designer choices in consideration of the many practical aspects which come into play and which typically generate a conflict between safety requirements and economic needs. This renders the design effort an optimization one aiming at finding the best compromise solution.

The geothermal power plant is a component of the cascaded geothermal energy utilization system, and is used to convert the energy of the geothermal water into electrical energy using CO_2 as working fluid. The elements of the power plant are the following: heat exchangers to vaporize and condense the CO_2, a reciprocating engine connected with the electric generator, a make-up and expansion CO_2 tank, and a CO_2 pump. (Fig. 1).

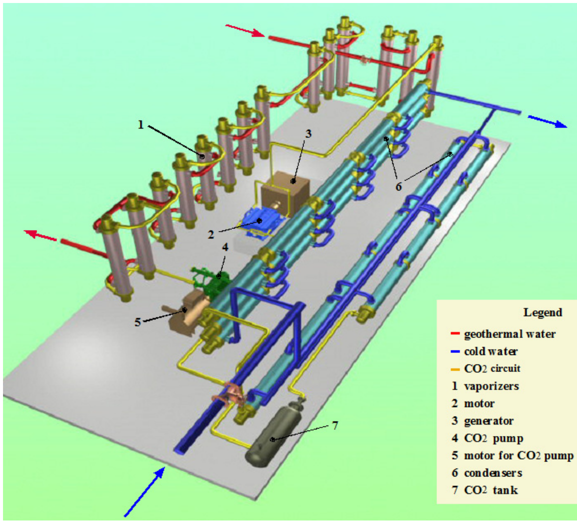
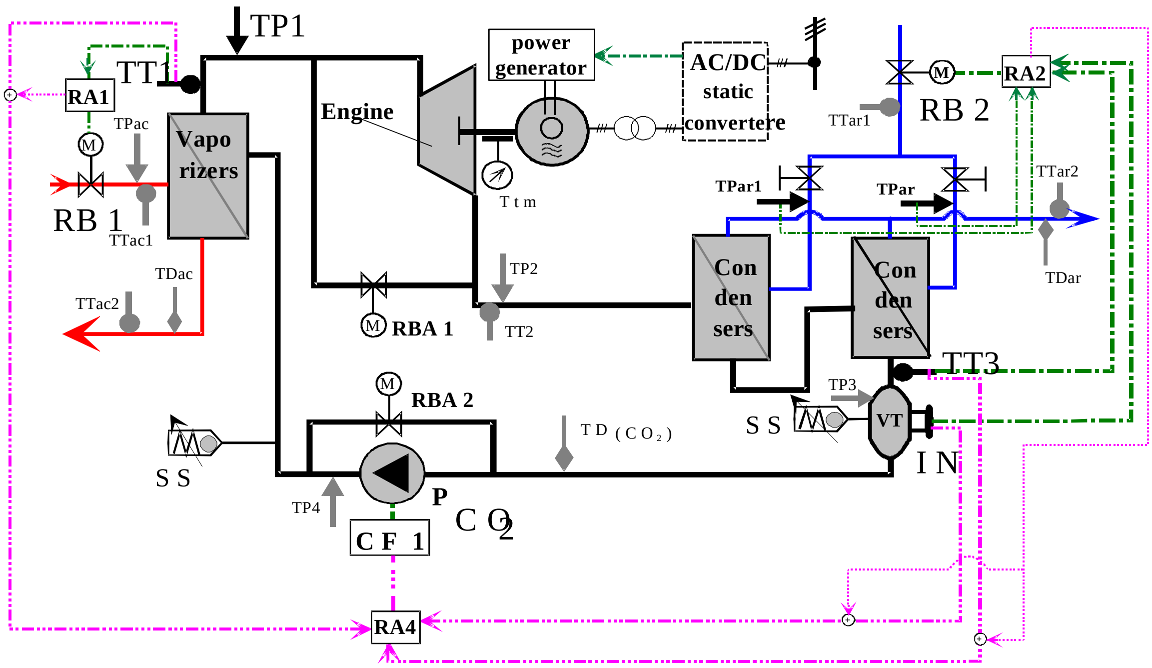


Fig. 1

3. THE RELIABILITY MODEL OF THE GEOTHERMAL SYSTEM

We analyzed the system considering that the vaporizers system contains 30 vaporizers. The vaporizers system and condensers is a series-parallel connection, connectors system is a series connection and motor, generator, CO2 pump and motor for CO2 pump are 2 of 3 connection (or 3 of 4 connection). We take for analyze a vaporizers system with 30 vaporizers and the total number of runs was 10000. The reliability, that is the percentage of successful runs recorded in the simulation was calculated by using the AVERAGE function applied to the columns where were recorded the results of individual Monte Carlo runs. In our case, the resulting reliability was: 97,435% (Popescu D. et al., 2005).

In Fig. 6 we have the entire system RBD [2].



RA - controller
CF - frequency converter
TT - temperature transducer
TP - pressure transducer
TD - flowrate transducer

Ttm – rotational speed transducer
RB - control valve
VT - CO_2 tank
IN - level indicator
SS - safety valve

Fig. 2 Geothermal power plant block scheme

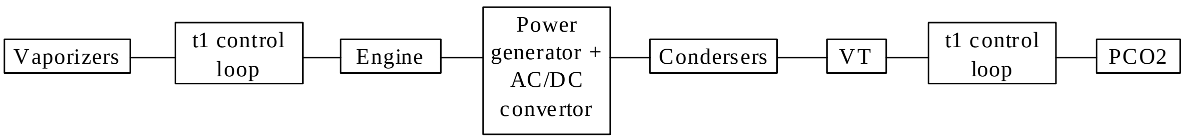


Fig. 3 RBD for the control system

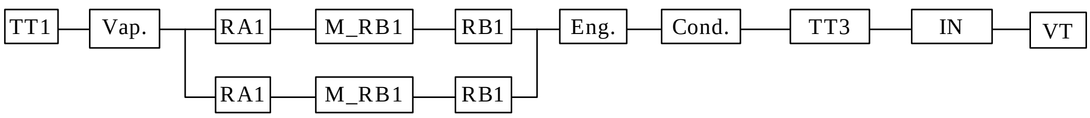


Fig. 4 RBD for the t1 control loop

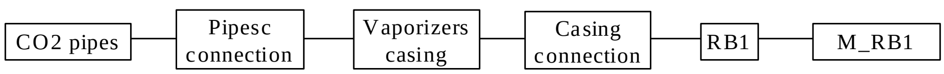


Fig. 5 RBD of vaporizers

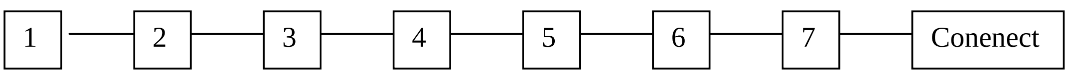


Fig. 6

4. THE RELIABILITY ANALYSIS FOR THE PHASED MISSION SYSTEM

Let consider the entire geothermal plant as a system that has to acts in different phases and let use the Markov chains for solving the resulted system.

So, there are three phases for the geothermal plant:

1. During autumn and spring, when it has to ensure only the manager water

2. During winter when it has to ensure the heating process and manager water

3. And during the summer when it has to ensure the cooling process and the manager water

We distinguish three jobs for our geothermal plant: the heating (noted by A), the cooling (noted by B) and the ensuring of manager water (noted by C). These are given in Fig. 7.

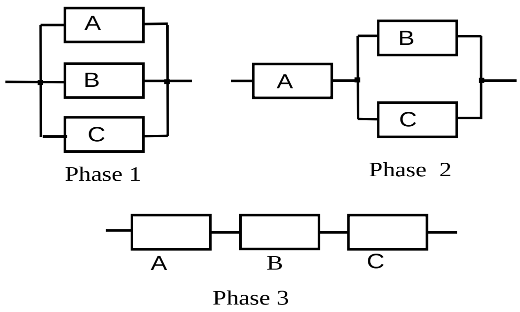


Fig. 7

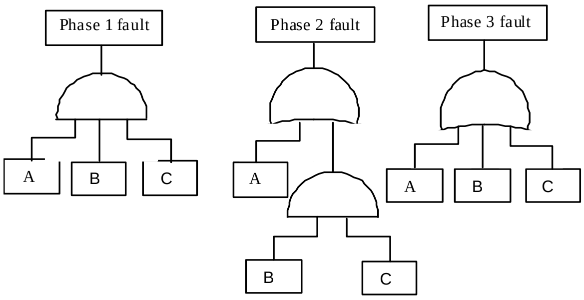


Fig. 8

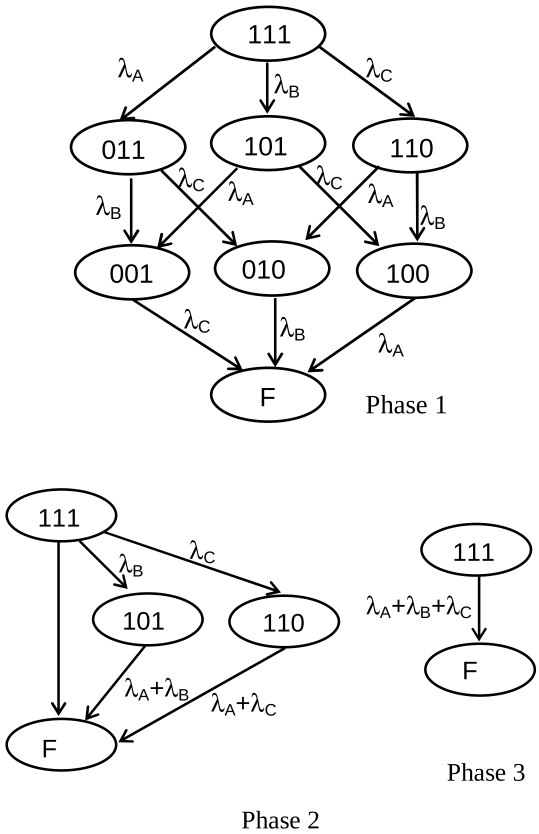


Fig. 9

The Fault tree model for these three phases is in Fig. 8 and the Markov model of each phase is in Fig. 9.

If the system's component doesn't have a dynamic behavior (transient errors, imperfect reconfiguration) then we can adopt a standard combinatorial approach for analyzing the phased missions.

The simplest method (Law, A. M., Kelton, D.W., 1991) uses a serial connection for all the reliability blocks of each phased mission and then suppose the solving of the system's reliability at the end of each phase. But, it is a conservative approach.

A more exact approach suppose to build a block diagram for an equivalent system in the following way: in the block diagram of phase i, the C component is replaced by a connected series of s-independent components $C_1, C_2, ... C_i$. The failure probabilities associated with the C_i component is the probability that the component have survived to the i'th given phase and also have survived to all anterior phases. This is an exact method, bu it is an expensive one; because the fault tree solution grows exponential with the number the of added components.

4.1 The Markov combined model

The usual Markov approach for phased missions, supposes to sequential solve the Markov model of each phase. It uses the probabilities of the final states of mission i as initial probabilities for the mission i+1 states.

The heteregenuous Markov chains will be used in the situations when the moments for phases change are random. But the best solution is Smotherman approach.

I will present a model that combine important aspects of the two previous approaches and permit to generate and technical solve the model in an automatic manner (Dugan, J.B., 1991).

It uses the fault tree model from the combinatorial approach as a description language for each phase prescriptions. Then this model is automatically transformed in a Markov model. The moments of phases change are dynamic, so the probability of the final state is transformed also automatically in the probability of the initial state. Finally, as in the heteregenuous Smotherman technique, a single model is solved; but it is important to note that it is not considered the situation of random changing of phases.

In ord combine all the three models in a single model, we can add a multiply factor to each tranzition – with a tag depending on the phase it belongs. That is, for the tranzitions of phase i, each tranzition will be multiply by Φ_i. It results a combined Markov chain whose state space is the union of the three separate phases and whom tranzitions is the sum of the tranzition of each separate phase.

The combined model is in Fig. 10, where Φ_i is the tag for the tranzitions that belongs to phase i.

Once generated, this model can be solved by using a standard numnerical method, with the following change: for the time solution of the phase i $(T_{i-1} \le t \le T_i)$, Φ_i is set to 1 and all the others Φ_j $j \ne i$ are 0. This assignement filters all the tranzitions that does not belongs to the current phase.

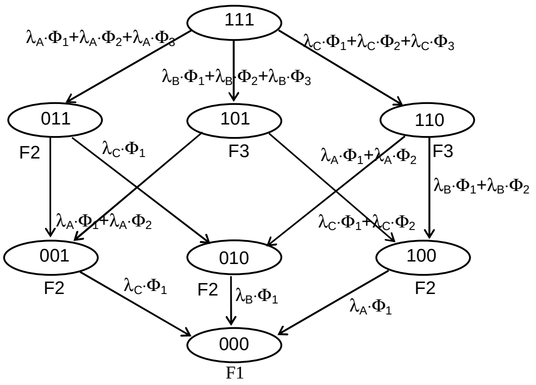


Fig. 10

The resulted model is still Markov, but it is no more omogen (the tranzition moments are dependent on the global time.

4.2. The model specifications

The converting process of a fault tree in a Markov chane is give below:

Notations:

c - the component number in the system

n_i - the number of type i components

u_i - the failure rate for the component type i

s - c-tuple ce that represents a state in Markov chane

s_i - the number of operational components of type i from the state

m - the phase number for the mission

The conversion algorithm is the following:

As long as the queue is not empty, execute:
Begin
Take the term from the top of the queue and named it as sourse state
For $i = 1$ to c execute:
Begin
Simulate the fault of component i and determine
The rseult state (state_dest)
If state_dest is not in fault and state_dest is not
Yet included in the queue
Then put the state_dest in queue for a following processing
Record the tranzition rate between state_source and
state_dest $(s_i \cdot u_i)$
End
End

Fig. 11

Beginning with the fault trees of each separate phase, we link the events from the top of each phase with a tranfer gate and the events from the buttom which represent the same component are treated as common events. It is important that we don't have to create new components for representing the phased mission.

În Fig. 12 is the combined event tree of our example.

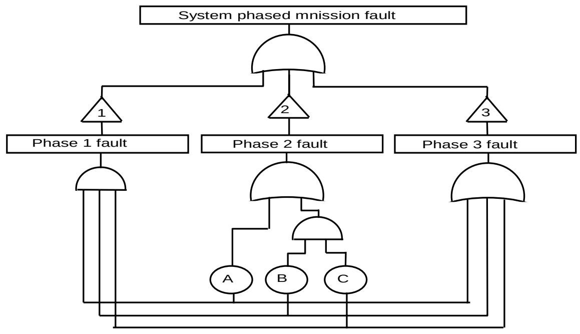


Fig. 12

The presented model is used for computing the MTBF, for calculating the possibilities of finalizing with success the phased misions.

It is usefull for the reliability analysis of the geothermal plant system because the phases are repeated in time.

The system here considered consists of n = 7 nodes. In Fig. 13 we give the failure rates and the costs for the system components.

Component i	Purchase cost Ci [10^3 \$]	Failure rate λ_i [10^{-3} y^{-1}]
1	67.5	4.8
2	54	4,3
3	81	4,6
4	45	3.6
5	85.5	3.6
6	58.5	3.7
7	13.5	3.8
8	45	4

Fig. 13

The genetic algorithm procedure described in Tillman, F. A., et al. (1977) has been applied to our geothermal system. Genetic algorithms can be very useful in solving complex design problems. The simple case considered here has allowed us to compute the objective function analytically and the genetic algorithm was able to converge very rapidly, in a few iterations.

We considered 75 generations for a population of 100 chromosomes and the evolution was made with a probability for crossovers set as $p_c = 0{,}25$ and the probability for the simple mutation set as $p_m = 0{,}01$, so, on average, 1% of total bit of population would undergo mutation.

Fig. 14 reports the schematic for the optimal configuration found by the genetic algorithm procedure, which converges only after a few iterations (C. Popescu, et al., 2005).

However, for more realistic models we can use a Monte Carlo method for its evaluation.

The Functional Reliability Block Diagram (RBD) of the system under investigation is first transformed into a table in an Excel Spreadsheet. Each cell within the table corresponds to a specific block in the RBD. Formulae for failure times entered into these cells are in accordance with the failure time distribution of the corresponding block and can follow exponential, normal, lognormal or Weibull distribution. The Excel pseudo random number generator is used to simulate failure times of individual units or modules in the system. Logical expressions are then used to determine system success or failure. Excel's macro feature enables repetition of the scenario thousands of times while automatically recording the failure data.

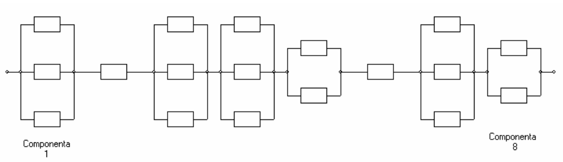


Fig. 14

After a number of 10000 runs, the reliability for the geothermal plant, was obtained as: 97,435 (D.Popescu et al., 2005).

By applying the proposed approach for computing the phased mission system reliability the results obtained by us were: 98.02. We considered six month for the phase C, two months for phase B and 5 months for phase A.

5. CONCLUSION

In fact the mission for a geothermal power plant consists of several phases. So, I considered in this paper the entire geothermal plant as a system that has to act in different phases and I proposed to use the Markov chains for solving the reliability of the resulted phase mission system.

So, there are three phases for the geothermal plant:

- During autumn and spring, when it has to ensure only the manager water
- During winter when it has to ensure the heating process and manager water
- And during the summer when it has to ensure the cooling process and the manager water

The system configuration, operational requirements for individual components, success criteria and stress on the components, can change from phase to phase. Furthermore, the duration of any phase can use deterministic or random models. All these changes and possibilities affect the system reliability. First I considered the problem of optimizing the system configuration in order to accomplish a maximum reliability in conditions of a minimum value for the cost, and then I computed the reliability that results for the entire system who acts as a phases mission system. The results obtained using the approach of considering the geothermal plant as a phased mission system are concludent.

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