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A Reliability Forecast of a Parallel Power Supply Plant Using Boolean Function Technique Under Exponential and Weibull Distributions

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ABSTRACT: *The most necessary part of our day to day life is electricity. The primary purpose of a power supply plant is to convert mechanical energy into electrical energy in order to supply power to the electrical grid for the consumer's needs. In this research paper deals with a power supply plant with three generators which are connected with parallel redundancy. Although, only one generator is sufficient for supplying power to the consumer's needs. The authors' of this research paper intend to evaluate and forecast the system's reliability parameters, and have shown the practical utility of the work done with numerical examples and graphical illustrations.*

KEYWORDS: *Reliability, Parallel Redundancy, Probability, Exponential Time Distribution, Weibull Distribution, M,T.T.F. (Mean Time to Failure).*

I. INTRODUCTION

Today scenario energy crisis and environmental pollution have become two critical concerns in the last decade [1]. In the electric power industry, for instance, Internet of things (IoT) [2] technology will make sure cost savings and create new products. IoT solutions in logistics will cut costs, increase transparency in supply chains, and decrease the need for human work. IoT elements like smart grid technology [3] can significantly ameliorate the reliability of power systems. In terms of power generation, Internet of things (IoT) adoption will entail equipping critical units at power plants with diagnostic systems [4]. At power supplies plants, Internet of things (IoT) systems also enable users to receive data on equipment operation in real time and take informed decisions on maintenance and repairs, as well as optimize the timing of equipment shutdowns and minimize the risk of incidents [5]. In this research paper, the authors' have considered a power supply plant for its reliability [6] forecast. In this power plant, power is generated by the generators namely $G_{1,}$ G_2 and $G_{3.}$ These generators are working in parallel redundancy [7]. These power generators are connected by switch Boards $SD_{1,}$ $SD_{2;}$ sub power board SPB; output board OPB. All these components are connected with hundred percent reliable cables C_1, C_2------C_{10}. The aim of plant is to supply the power generated by generators to critical consumer [8] through output board OPB. Only one generator is sufficient to fulfill the requirement of consumer. On failure of one generator other has to work to fulfill the same requirement.

The supply of power can fail if at least one component in all the routes of supply, fails. System Configuration has shown in fig.-1. The reliability of every component of power plant is known in advance. Mathematical logic [9] and Boolean function technique have been used to formulate and solve the symbolic model. The reliability of power plant is calculated considering that failure times of various components of power plant follow exponential and Weibull time distribution. Moreover an important reliability parameter M.T.T.F. [10] has also been calculated for exponential failure time distribution. A numerical example with graphical illustration has given at the end to highlight the obtained results. Afterward an emerging technology, Blockchain [11] has been widely adopted in many domains for its well-known advantages [12]. Blockchain was indeed flawed when it first emerged. The application fields of the Blockchain technology include finance, Internet of Things [2], public social services, reputation system, security and privacy, and so on [13]. The integration of Blockchain technology into energy trading is a novel and promising area of research, and many studies have made efforts in this regard [14]. At the present time, Blockchain based energy trading is not just a theoretical topic, application of Blockchain in the field of energy trading has achieved significant success. Blockchains [15] in local energy markets can incentivize end-consumer participation. As a outcome, consumers are exposed to the real cost of energy, which might result in more rational energy consumption or suitable price signals for demand response [16].

II. ASSUMPTIONS

The following assumptions have been associated with this model

(i) Initially, all the components of power plant are new and are working with full efficiency.
(ii) There is no repair facility to the failed component.
(iii) The supply of power can fail only if at least one component in all routes of power supply fails.
(iv) Failures are statistically independent.
(v) The state of each component and of the whole power plant can be either good or bad.
(vi) The cables used to connect the different components of power plants, are hundred percent reliable.
(vii) The reliability of each component is pre-calculated.

III. NOTATIONS

The following notations have been used throughout this model:

x_k : $k^{th}\ state.$

$k = 1,2,3$: Generators G_1, G_2 and G_3

$k = 4,5$: Switch Boards SD_1 and SD_2

$k = 6$: Sub power Board SPB

$k = 7$: Output Board OPB

x'_k : Negation of $k^{th}\ state.$

$$x_k = \begin{cases} 0, & in\ failed\ state \\ 1, & in\ good\ state, \qquad k = 1,2,--,7. \end{cases}$$

R_S : Reliability State

$\wedge, \vee$: Conjunction, Disjunction

$C_1, C_2, --, C_{10}$: Cables used to connect different components of power plant.

IV. FORMULATION OF MATHEMATICAL MODEL

By using B.F. Technique, one may obtain the following logical [17] matrix, which gives the conditions of capability of successful operation of the power plant under consideration:

$$F(x_1, x_2, ---, x_7) = \begin{pmatrix} x_1 & x_4 & x_7 & \\ x_1 & x_6 & x_7 & \\ x_1 & x_5 & x_6 & x_7 \\ x_2 & x_6 & x_7 & \\ x_2 & x_4 & x_6 & x_7 \\ x_2 & x_5 & x_6 & x_7 \\ x_3 & x_5 & x_7 & \\ x_3 & x_6 & x_7 & \\ x_3 & x_4 & x_6 & x_7 \end{pmatrix} \qquad (1)$$

A. Solution of the Model

Applying algebra of logic, equation (1) may be rewritten as

$$F(x_1, x_2, ---, x_7) = |x_7 \quad \wedge \quad f(x_1, x_2, ---x_7| \qquad (2)$$

where,

$$f(x_1, x_2, ---, x_6) = \begin{pmatrix} x_1 & x_4 & \\ x_1 & x_6 & \\ x_1 & x_5 & x_6 \\ x_2 & x_6 & \\ x_2 & x_4 & x_6 \\ x_2 & x_5 & x_6 \\ x_3 & x_5 & \\ x_3 & x_6 & \\ x_3 & x_4 & x_6 \end{pmatrix} = \begin{pmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \\ M_5 \\ M_6 \\ M_7 \\ M_8 \\ M_9 \end{pmatrix} \qquad (3)$$

where,

$M_1 = (x_1 \quad x_4) \quad , \quad M_2 = (x_1 \quad x_6) \quad$ *and so on.*

Using orthogonalization algorithm, equation (3) can be written as

$$f(x_1, x_2, --, x_6) = \begin{pmatrix} M_1 \\ M'_1 & M_2 \\ M'_1 & M'_2 & M_3 \\ M'_1 & M'_2 & M'_3 & M_4 \\ M'_1 & M'_2 & M'_3 & M'_4 & M_5 \\ M'_1 & M'_2 & M'_3 & M'_4 & M'_5 & M_6 \\ M'_1 & M'_2 & M'_3 & M'_4 & M'_5 & M'_6 & M_7 \\ M'_1 & M'_2 & M'_3 & M'_4 & M'_5 & M'_6 & M'_7 & M_8 \\ M'_1 & M'_2 & M'_3 & M'_4 & M'_5 & M'_6 & M'_7 & M'_8 & M_9 \end{pmatrix} \qquad (4)$$

By making use of algebra of logic, one can obtain the following results

$M_1 = (x_1 \quad x_4) \quad , \quad M_2 = (x_1 \quad x_6)$

$$M'_1 = \begin{pmatrix} x'_1 & \\ x'_1 & x'_4 \end{pmatrix} \qquad (5)$$

$$M'_1 M_2 = \begin{pmatrix} x'_1 & \\ x'_1 & x'_4 \end{pmatrix} \wedge (x_1 \quad x_6) = (x_1 \quad x'_4 \quad x_6) \qquad (6)$$

Similarly,

$$M'_1 M'_2 M_3 = (x_1 \quad x'_4 \quad x_5 \quad x_6) \qquad (7)$$

$$M'_1 M'_2 {M_3}' M_4 = (x'_1 \quad x_2 \quad x_6) \qquad (8)$$

$$M'_1 M'_2 {M_3}' M'_4 M_5 = (x'_1 \quad x_2 \quad x_4 \quad x_6) \qquad (9)$$

$$M'_1 M'_2 {M_3}' M'_4 M'_5 M_6 = (x'_1 \quad x_2 \quad x_5 \quad x_6) \qquad (10)$$

$$M'_1 M'_2 {M_3}' M'_4 M'_5 M'_6 M_7 = (x'_1 \quad x'_2 \quad x_3 \quad x_5) \qquad (11)$$

$$M'_1 M'_2 {M_3}' M'_4 M'_5 M'_6 M'_7 M_8 = (x'_1 \quad x'_2 \quad x_3 \quad x'_5 \quad x_6) \qquad (12)$$

$$M'_1M'_2M_3{}'M'_4M'_5M'_6M'_7M'_8M_9 = (x'_1 \quad x'_2 \quad x_3 \quad x_4 \quad x'_5 \quad x_6) \qquad (13)$$

By making use of equations (5) through (13), equation (4) becomes

$$f(x_1, x_2, --, x_6) = \begin{pmatrix} x_1 & x_4 & & & & \\ x_1 & x'_4 & x_6 & & & \\ x_1 & x'_4 & x_5 & x_6 & & \\ x'_1 & x_2 & x_6 & & & \\ x'_1 & x_2 & x_4 & x_6 & & \\ x'_1 & x_2 & x_5 & x_6 & & \\ x'_1 & x'_2 & x_3 & x_5 & & \\ x'_1 & x'_2 & x_3 & x'_5 & x_6 & \\ x'_1 & x'_2 & x_3 & x_4 & x'_5 & x_7 \end{pmatrix} \qquad (14)$$

By using equation (14), equation (2) becomes

$$F(x_1, x_2, --, x_7) = \begin{pmatrix} x_1 & x_4 & x_7 & & & & \\ x_1 & x'_4 & x_6 & x_7 & & & \\ x_1 & x'_4 & x_5 & x_6 & x_7 & & \\ x'_1 & x_2 & x_6 & x_7 & & & \\ x'_1 & x_2 & x_4 & x_6 & x_7 & & \\ x'_1 & x_2 & x_5 & x_6 & x_7 & & \\ x'_1 & x'_2 & x_3 & x_5 & x_7 & & \\ x'_1 & x'_2 & x_3 & x'_5 & x_6 & x_7 & \\ x'_1 & x'_2 & x_3 & x_4 & x'_5 & x_6 & x_7 \end{pmatrix} \qquad (15)$$

Since, R.H.S. of equation (15) is a disjunction of pair wise disjoint [18] conjunctions, so that the reliability of the considered power plant is given by

$$R_S = P_r[F(x_1, x_2, ---, x_7)] = 1$$

$$\begin{aligned} R_S = R_7[&R_1R_4 + R_1(1-R_4)R_6 + R_1(1-R_4)R_5R_6 + (1-R_1)R_2R_6 + (1-R_1)R_2R_4R_6 + (1-R_1)R_2R_5R_6 \\ &+ (1-R_1)(1-R_2)R_3R_5 + (1-R_1)(1-R_2)R_3(1-R_5)R_6 + (1-R_1)(1-R_2)R_3R_4(1-R_5)R_6] \end{aligned}$$

$$\begin{aligned} \Rightarrow R_S = R_7[&R_1R_4 + R_1R_6 - R_1R_4R_6 + R_1R_5R_6 - R_1R_4R_5R_6 + R_2R_6 + R_2R_5R_6 - R_1R_2R_6 - R_1R_2R_4R_6 - R_1R_2R_5R_6 + R_3R_5 \\ &+ R_3R_6 + R_3R_4R_6 - R_3R_5R_6 + R_2R_4R_6 - R_3R_4R_5R_6 - R_1R_3R_5 - R_1R_3R_6 + R_1R_3R_5R_6 - R_1R_3R_4R_6 \\ &+ R_1R_3R_4R_5R_6 - R_2R_3R_5 - R_2R_3R_6 + R_2R_3R_5R_6 - R_2R_3R_4R_6 + R_2R_3R_4R_5R_6 + R_1R_2R_3R_5 + R_1R_2R_3R_6 \\ &- R_1R_2R_3R_5R_6 + R_1R_2R_3R_4R_6 - R_1R_2R_3R_4R_5R_6 \end{aligned} \qquad (16)$$

Where, $R_1, R_2, --, R_7$ are the reliabilities [19] of the components of the considered power plant corresponding to [8] the states $x_1, x_2, --, x_7$ respectively.

V. SOME PARTICULAR CASES

Case I: If Reliability of Each Component of Considered Power Plant is being R, Then Equation (16) Yields:

$$R_S = R^3[5 - 3R - 2R^2 + 2R^3 - R^4] \qquad (17)$$

Case II: When Failure Rates Follow Weibull Distribution:

Let failure rates of the state's $x_1, x_2, - - x_7$,are λ_1, λ_2 ----- λ_7 respectively [9], then from equation (16) reliability of power plant at instant 't' is given by

$$R_{SW}(t) = \sum_{i=1}^{16} \exp.\{-b_i t^p\} - \sum_{j=1}^{15} \exp.\{-a_j t^p\} \qquad (18)$$

Where, p is a positive parameter and b_i's and a_j's are mentioned as below

$b_1 = \lambda_1 + \lambda_4 + \lambda_7$
$b_2 = \lambda_1 + \lambda_6 + \lambda_7$
$b_3 = \lambda_1 + \lambda_5 + \lambda_6 + \lambda_7$
$b_4 = \lambda_2 + \lambda_6 + \lambda_7$
$b_5 = \lambda_2 + \lambda_4 + \lambda_6 + \lambda_7$
$b_6 = \lambda_2 + \lambda_5 + \lambda_6 + \lambda_7$
$b_7 = \lambda_3 + \lambda_5 + \lambda_7$
$b_8 = \lambda_3 + \lambda_6 + \lambda_7$
$b_9 = \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7$
$b_{10} = \lambda_1 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7$
$b_{11} = \lambda_1 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$
$b_{12} = \lambda_2 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7$
$b_{13} = \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$
$b_{14} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_5 + \lambda_7$
$b_{15} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_6 + \lambda_7$
$b_{16} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7$
$a_1 = \lambda_1 + \lambda_4 + \lambda_6 + \lambda_7$
$a_2 = \lambda_1 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$
$a_3 = \lambda_1 + \lambda_2 + \lambda_6 + \lambda_7$
$a_4 = \lambda_1 + \lambda_2 + \lambda_4 + \lambda_6 + \lambda_7$
$a_5 = \lambda_1 + \lambda_2 + \lambda_5 + \lambda_6 + \lambda_7$
$a_6 = \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7$
$a_7 = \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$
$a_8 = \lambda_1 + \lambda_3 + \lambda_5 + \lambda_7$
$a_9 = \lambda_1 + \lambda_3 + \lambda_6 + \lambda_7$
$a_{10} = \lambda_1 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7$
$a_{11} = \lambda_2 + \lambda_3 + \lambda_5 + \lambda_7$
$a_{12} = \lambda_2 + \lambda_3 + \lambda_6 + \lambda_7$
$a_{13} = \lambda_2 + \lambda_3 + \lambda_4 + \lambda_6 + \lambda_7$
$a_{14} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_5 + \lambda_6 + \lambda_7$
$a_{15} = \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 + \lambda_5 + \lambda_6 + \lambda_7$

Case III: When Failure Rates Follow Exponential Time Distribution:

Exponential distribution is a particular case of Weibull distribution [20]. Thus, the reliability of power plant [18] under Exponential distribution at time't', can be obtained by putting the [21] value of the variable $\boxed{p = 1}$, in equation (18) as:

$$R_{SE}(t) = \sum_{i=1}^{16} \exp.\{-b_i t\} - \sum_{j=1}^{15} \exp.\{-a_j t\} \qquad (19)$$

Where, bi's and a_j's are stated earlier.

Also, an important reliability parameter is M.T.T.F. [19] (Mean Time to Failure), in this case, it will be given as:

$$\mathrm{M.T.T.F.} = \int_0^\infty \mathrm{R_{SE}}\,(\mathrm{t})\,\mathrm{dt} = \sum_{\mathrm{i}=1}^{16} \frac{1}{\mathrm{b_i}} - \sum_{\mathrm{j}=1}^{15} \frac{1}{\mathrm{a_j}} \qquad (20)$$

VI. NUMERICAL COMPUTATION

Setting the values of the failure rates’$\lambda_1 = \lambda_2, \lambda_3, --, \lambda_7 = s$, in equations (18) through (20), one can obtain [22] the reliability and MTTF of the system model [23].

$$R_{SW}(t) = 5e^{-3st^p} - 3e^{-4st^p} - 2e^{-5st^p} + 2e^{-6st^p} - e^{-7st^p} \qquad (21)$$

$$R_{SE}(t) = 5e^{-3st} - 3e^{-4st} - 2e^{-5st} + 2e^{-6st} - e^{-7st} \qquad (22)$$

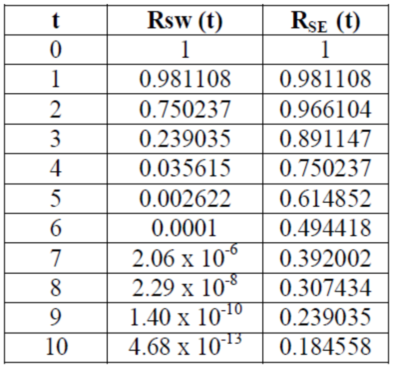
$$\text{and, M.T.T.F.} = \frac{1}{s}\left[\frac{5}{3} - \frac{3}{4} - \frac{2}{5} + \frac{2}{6} - \frac{1}{7}\right] = \frac{0.7071429}{s} \qquad (23)$$

In (21) , put p = 2 , s = 0.1 and t = 0,1,2 --------;

In (22) , put s = 0.1 and t = 0,1,2 ----------------;

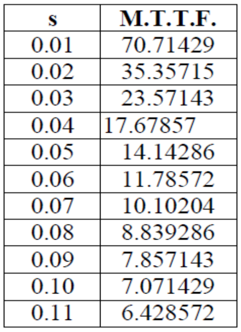
In (23) , put s = 0.01, 0.02 ------------------------;
One can compute the tables 1 and tables 2 and sketch the graphs as shown in figure 1 and 2, respectively.

Table 1. The R_{sw} (t) and R_{se} (t) Data



t	Rsw (t)	R_{SE} (t)
0	1	1
1	0.981108	0.981108
2	0.750237	0.966104
3	0.239035	0.891147
4	0.035615	0.750237
5	0.002622	0.614852
6	0.0001	0.494418
7	2.06×10^{-6}	0.392002
8	2.29×10^{-8}	0.307434
9	1.40×10^{-10}	0.239035
10	4.68×10^{-13}	0.184558

Table 2. The s and M.T.T.F. Data



s	M.T.T.F.
0.01	70.71429
0.02	35.35715
0.03	23.57143
0.04	17.67857
0.05	14.14286
0.06	11.78572
0.07	10.10204
0.08	8.839286
0.09	7.857143
0.10	7.071429
0.11	6.428572

VII. GRAPHICAL STUDY OF THE SYSTEM MODEL

The shown in the figure 1 graph has been drawn to the corresponding [24] values of table 1, and it shows that the reliability of the power plant [25] decreases in such a manner that, as we make increases in the time't' for Weibull and exponential time distributions.

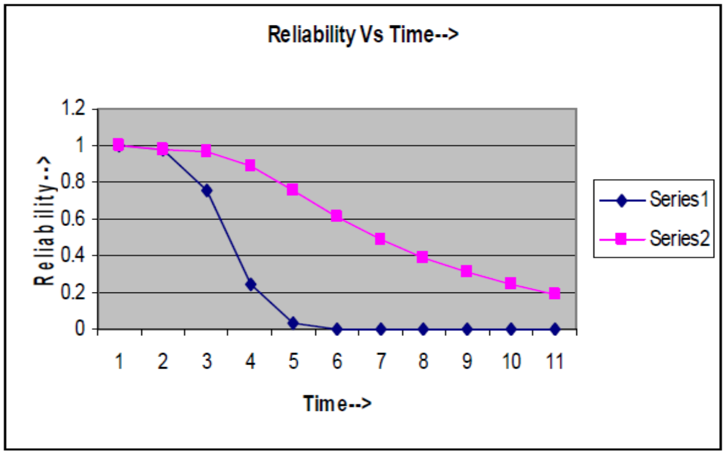


Fig 1. The Reliability vs Time Graph

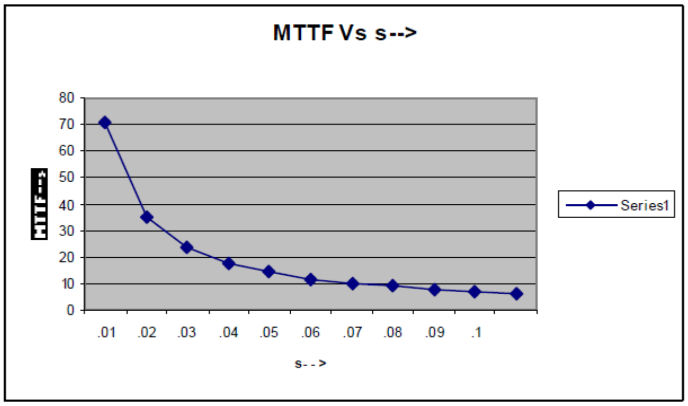


Fig 2. The MTTF vs s---->

A critical examination of graph reveals that $R_{sw}(t)$ [26] decreases rapidly with increase in time while $R_{SE}(t)$ decreases in a uniform way. The shown in the figure 2 graph has been drawn to the corresponding values by of table 2, and it shows that, how the [27] M.T.T.F. of the [19] power plant decreases with increase in failure rate's'. A critical examination [28] of graph reveals that for s = 0.01 to 0.04, the M.T.T.F. decreases very rapidly [29], but after s = 0.05 it decreases approximately in a uniform manner.

VIII. CONCLUSION

In this paper, we are considered a power plant for the analysis of its reliability forecast. Three generators which constitute the power plant are connected in parallel redundancy to improve the reliability of the system. Mathematical logic and Boolean function technique has been used to formulate and solve the symbolic model. Several reliability state(s), such as Weibull distribution and Exponential time distribution have been obtained to predict the system's ability. An important reliability parameter, which is Mean Time to Failure (M.T.T.F.) of the power plant, has also been analyzed to predict the future behavior of the system.

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