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Reliability Approach of a Compressor System using Reliability Block Diagrams

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ABSTRACT

Industry systems which use compressors are a sensitive subject in terms of reliability because these products can induce instability due to their complexity and numerous architectural options. These systems bust be under continuous supervision in order to eliminate unwanted failures and improve the capacity of the system. This paper presents a reliability analysis of such a system using reliability block diagrams (RBD). The aim of the analysis is to provide conclusive information about its constituent components and to identify the critical issues.

Key words: Compressor System, Reliability, Reliability Block Diagram, Rbd Modeling, Mtbf, Failure

1. INTRODUCTION

Compression equipments are used throughout the industry around the world like chemical, oil and gas, automotive, manufacturing and others. Having a big part in the industry these systems must be carefully designed in order to achieve stability and reliable operation [1]. Because these systems have numerous components in their architecture and also because there are many choices in terms of architectural definition, depending of the usage it is very hard to assess the reliability of such a system and moreover to provide a standardized model. Being so complex these systems can be analyzed using different reliability methods and techniques being therefore important to know what answers are needed in order to apply the correct analysis method. [1][2]

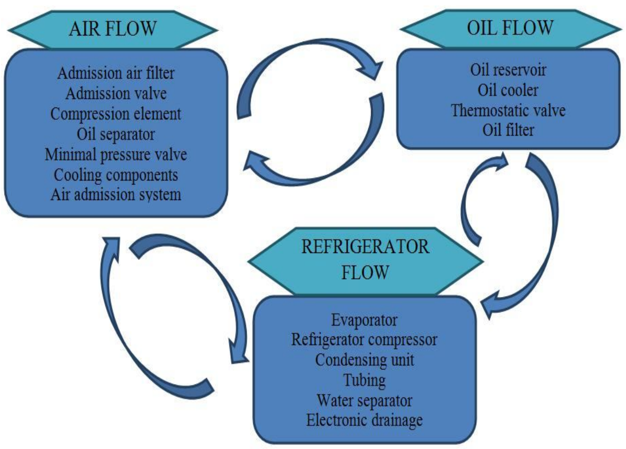

Figure 1: Compressor System

This paper presents a RBD modeling for a compressor system used in the Romanian light industry. The system which is presented in Figure 1 uses a compressor with oil injection driven by an electric motor. As can be seen from Figure 1 the system has been divided into 3 subsystems, air flow, oil flow and refrigerator flow, each having its associated components. This choice has been made to simplify the reliability analysis process [1][2][7].

2. RELIABILITY BLOCK DIAGRAMS (RBDS)

A product or system is made of components which are connected between them either logically or physically in order to perform its specified functions. The RBD (Reliability Block Diagram) method is a way of visually representing the relationship between a system's components and to calculate the reliability (mean time between failures and failure rate) and availability but also for showing how the reliability of a component contributes to the system's failure or success [2][5][6].

In the RBD representation there is often shown the logical connection which contributes to the system's function rather

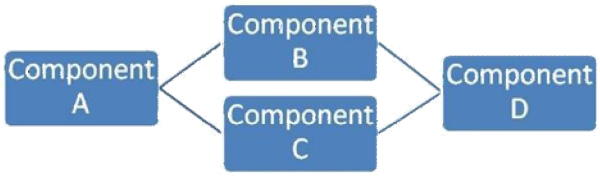

Figure 2: Reliability Block Diagram

than the physical connection. The RBD can also be used to assess the reliability of a single particular function and therefore the system can have multiple RBDs associated with it, considering different functions.

The overall reliability of a system can be influenced by the number of components in the system, by the operating conditions (temperature and environment), by the electrical stress and also by the way the components are connected between them.

Figure 2 below shows a RBD example for a simple system. The components are represented by blocks in the RBD having a failure rate associated with them and are connected either in series or in parallel configuration.

The series configuration means that failure in the path will lead to a total system failure while in the parallel configuration the components are redundant and it requires a failure in each of those components in order to have a total system failure. A failure in a single component of a parallel configuration means that the system continues to operate in good conditions or in a degraded mode until repair. This gives robustness to the system and this configuration can be used when having critical components in the system or when components have a high failure rate [3] [5] [8] [9] [10].

The RBD gives a more conclusive approach to the system reliability by modeling it as needed compared to the classical reliability prediction when a more complex system is to be analyzed. Having modeled the RBD, this can give a base input to develop a more detailed analysis like fault tree or event tree if required [6][8][9].

3. RELIABILITY MODELLING USING RBDS

A. Methodology

In order to complete the reliability analysis process a software tool has been used. This software tool, Windchill Quality Solutions, is a powerful assistant that can perform different analyses with different methods based on widely accepted reliability standards like MIL-HDBK-217, Telcordia or others [4].

To successfully model the system into an RBD a number of steps must be taken in Windchill. Therefore, the first step is to define the components of the system in order to have the base to perform the reliability prediction calculations.

The compressor system has been entered into the software as presented in Figure 3. It can be seen that the structure of the system is the same as the one presented in Figure. 1. The overall system has been divided into three subsystems: the air flow, the oil flow and the refrigerator flow. The compressors (air and refrigerator) have the electrical motor included. It can also be seen that two components, one from the oil flow and one from the refrigerator flow, are further divided into subcomponents: the thermostatic valve with the thermostat and the valve and the electronic drainage with the electronic module and the drainage. The reason behind this choice is to give a higher confidence for the results.

For each of these components there has been selected the category and subcategory and also the part number and

Name	Category	Subcategory	Part Number	System Tree Identifier
Electrical Motor Driven Compressors System			System	System
Air flow			AF	System1
Admission air filter	Filter	Air (Summary)	1	System1.1
Admission valve	Valve	Intake	2	System1.2
Minimal pressure valve	Valve	Pressure	5	System1.5
Oil separator	Separator	Oil	4	System1.4
Compression element	Compressor	Air	3	System1.3
Cooling components	Radiator	Tube,Small	6	System1.6
Air admission system	Pump	Pneumatic,Air	7	System1.7
Oil flow			OF	System2
Oil filter	Oil Filters	General	11	System2.11
Oil reservoir	Tank	Metal,Liquid,Oil	8	System2.8
Oil cooler	Radiator	Tube,Small	9	System2.9
Thermostatic valve			10	System2.10
Thermostat	Thermostat	Flow Control	10.1	System2.10.1
Valve	Valve	General	10.2	System2.10.2
Refrigerator flow			RF	System3
Water separator	Separator	Water,Aircraft Air Conditioning System	16	System3.16
Refrigerator compressor	Compressor	General	13	System3.13
Tubing	Tube Assembly	General	15	System3.15
Condensing unit	Condenser	Shell/Tube	14	System3.14
Evaporator	Evaporator	Coil,Direct Expansion	12	System3.12
Electronical drainage			17	System3.17
Drainage	Drain	(Summary)	17.1	System3.17.1
Electronical module	Module	Relay Circuit	17.2	System3.17.2

Figure 3: Compressor System Components

identifier as can be seen from the figure. These last two characteristics are used by the software for identification purposes between the software modules as links have to be made for the RBD modeling.

After the system has been entered into the software, the next step is to assign the specifications in terms of operation for each component. Having collected all this information the conditions and reliability standard by which the calculations are to be made can be specified:

- Calculation Model: MIL-HDBK-217-FN2
- Temperature: 40° C
- Environment: GB-Ground Benign (Nonmobile, temperature and humidity controlled environments readily accessible to maintenance; includes laboratory instruments and test equipment)
- Operational Duty cycle: 100% (System under continuous operation)

The last step into the prediction process is to run the program for the software to calculate the parameters. The results for the MTBF (mean time between failures), FR (failure rate) and Reliability captured from the software are presented in Figure 4. Having completed this process the next step is to model the RBD for the system.

We can see from Figure 4 that the MTBF and FR are presented for each individual component while the Reliability is shown only for the subsystems or systems. At a first look we can conclude that the system has a MTBF of under a year of continuous operation with the air and oil filters being the critical components. This is justified by the fact that these components are consumables and have to be changed periodically.

Also, it has to be specified that the reliability prediction assumes that the system is in a series connection configuration and the MIL-HDBK-217 usually gives a pessimistic prediction therefore we can assume that the system will operate in good conditions and without a failure for a full year. Nevertheless, as the system must be monitored and maintained at periodical time intervals.

Gathering the needed information the system can now be modeled into a RBD using the Windchill software.

The components have been transferred as blocks in the RBD module and connected as can be seen in Figure 5. Again, the same structure has been kept with the three subsystems: air flow, oil flow and refrigerator flow.

The air flow subsystem has 2 parallel connections because it has been identified in the architecture that a failure in one of the components will not lead to the total failure of the system (e.g. a failure into the air filter or valve will drive the system into a degraded mode but will still be capable of operation). The air admission component is the key element in this subsystem as a failure will lead to a system loss.

The components from the oil flow are all required for the system's success and therefore have been connected in a series configuration. If a failure occurs in one of these components the whole system will fail and will need repairs.

Moving forward, at the refrigerator flow subsystem, we can see again that we have 2 parallel connections where a failure will not lead to the loss of the system (e.g. evaporator or water separator). The tubing and the refrigerator compressor are key elements to this subsystem and in turn to the overall system. A failure occurrence in these components means that the system has be taken out of service and corrective maintenance actions have to be applied.

Name	Failure Rate, Predicted	MTBF, Predicted	Reliability, Predicted
Electrical Motor Driven Compressors System	162.191584	6166	0.983912
Air flow	65.374817	15296	0.993484
Admission air filter	33.018056	30286	#.#
Admission valve	2.272727	440000	#.#
Minimal pressure valve	5.639183	177331	#.#
Oil separator	10.767276	92874	#.#
Compression element	0.768979	1e+006	#.#
Cooling components	6.844065	146112	#.#
Air admission system	6.064531	164893	#.#
Oil flow	64.448608	15516	0.993576
Oil filter	46.724605	21402	#.#
Oil reservoir	2.567000	389560	#.#
Oil cooler	10.392602	96222	#.#
Thermostatic valve	4.764401	209890	0.999524
Thermostat	2.531224	395066	#.#
Valve	2.233177	447793	#.#
Refrigerator flow	32.368159	30895	0.996768
Water separator	6.590307	151738	#.#
Refrigerator compressor	12.038289	83068	#.#
Tubing	2.014265	496459	#.#
Condensing unit	5.211851	191870	#.#
Evaporator	4.630853	215943	#.#
Electronical drainage	1.882594	531182	0.999812
Drainage	0.962594	1e+006	#.#
Electronical module	0.920000	1e+006	#.#

Figure 4: Compressor System Reliability Calculation Results

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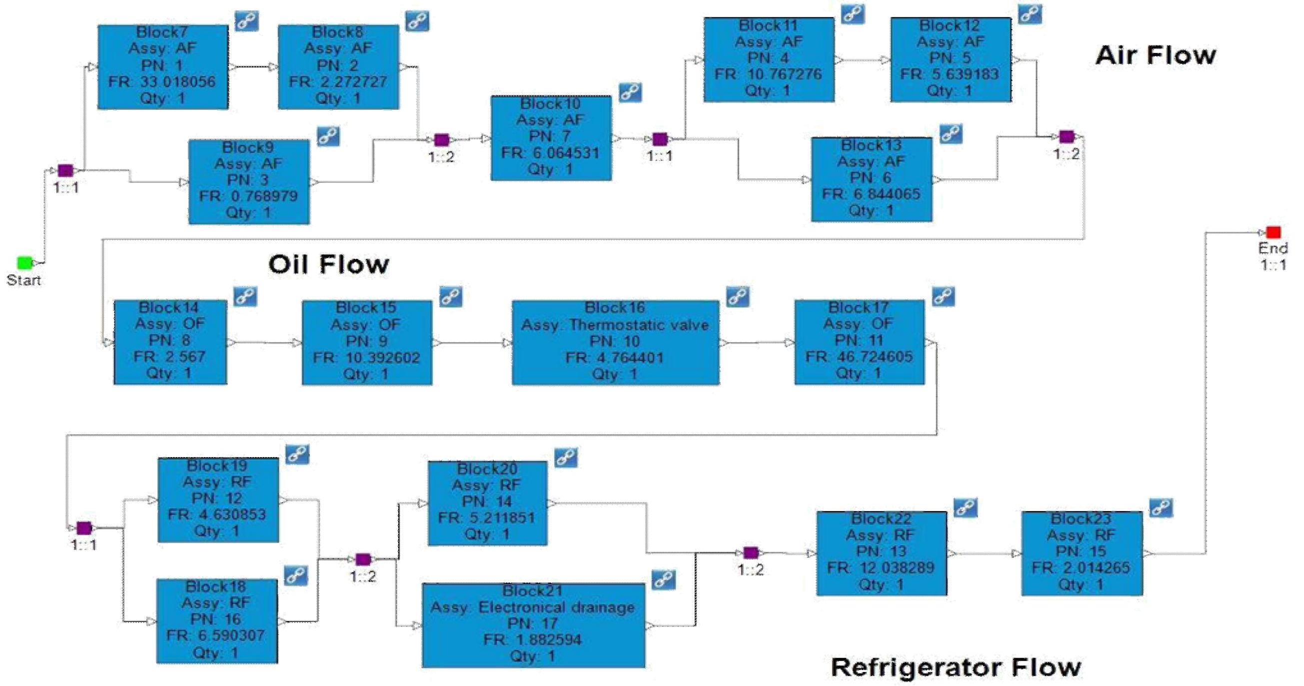
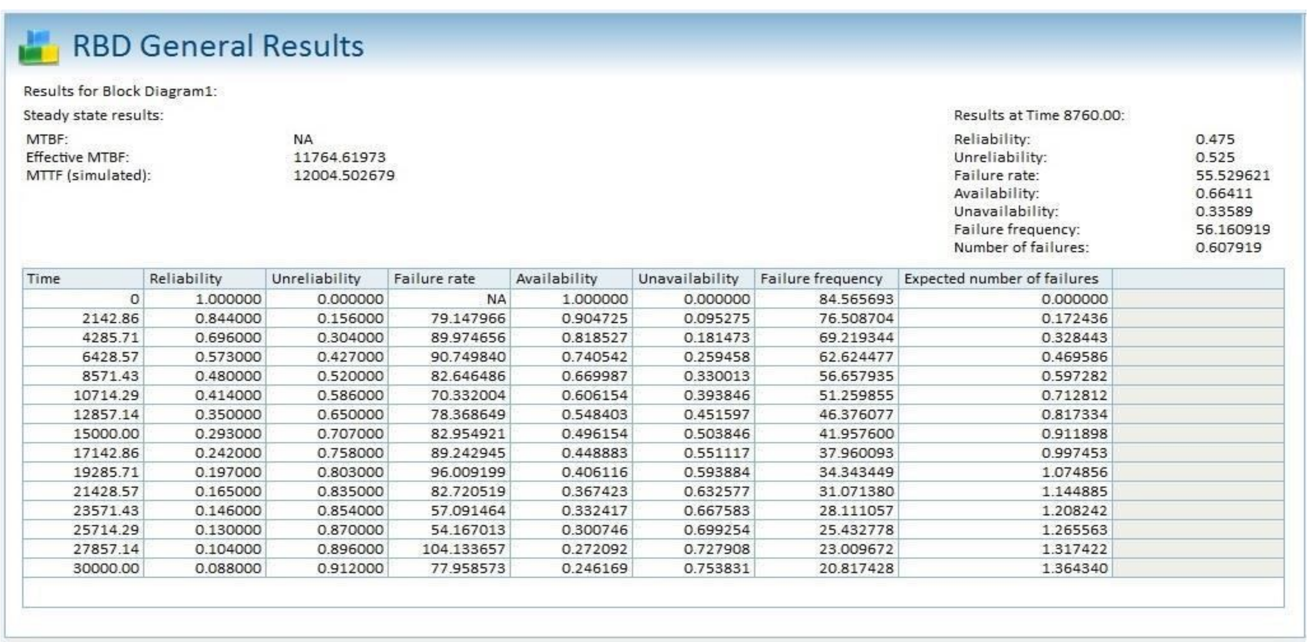


Figure 5: Compressor System RBD

The two components which were further divided into subcomponents in the prediction module have been entered here as single components in order to simplify the paths of the RBD. The calculations for the RBD have been made for a total of 30,000 hours of continuous operation.

Calculating the indicators for the RBD module we can see in Figure 6 that the results are different from the first case, the reliability prediction.

In addition, the RBD also calculates the availability and unavailability, unreliability, failure frequency and expected number of failures in time. It can be seen from the figure that now the MTBF has been greatly improved for this architecture and it is almost double, being 11,764 hours compared to the



RBD General Results

Results for Block Diagram1:

Steady state results:

MTBF:	NA
Effective MTBF:	11764.61973
MTTF (simulated):	12004.502679

Results at Time 8760.00:

Reliability:	0.475
Unreliability:	0.525
Failure rate:	55.529621
Availability:	0.66411
Unavailability:	0.33589
Failure frequency:	56.160919
Number of failures:	0.607919

Time	Reliability	Unreliability	Failure rate	Availability	Unavailability	Failure frequency	Expected number of failures
0	1.000000	0.000000	NA	1.000000	0.000000	84.565693	0.000000
2142.86	0.844000	0.156000	79.147966	0.904725	0.095275	76.508704	0.172436
4285.71	0.696000	0.304000	89.974656	0.818527	0.181473	69.219344	0.328443
6428.57	0.573000	0.427000	90.749840	0.740542	0.259458	62.624477	0.469586
8571.43	0.480000	0.520000	82.646486	0.669987	0.330013	56.657935	0.597282
10714.29	0.414000	0.586000	70.332004	0.606154	0.393846	51.259855	0.712812
12857.14	0.350000	0.650000	78.368649	0.548403	0.451597	46.376077	0.817334
15000.00	0.293000	0.707000	82.954921	0.496154	0.503846	41.957600	0.911898
17142.86	0.242000	0.758000	89.242945	0.448883	0.551117	37.960093	0.997453
19285.71	0.197000	0.803000	96.009199	0.406116	0.593884	34.343449	1.074856
21428.57	0.165000	0.835000	82.720519	0.367423	0.632577	31.071380	1.144885
23571.43	0.146000	0.854000	57.091464	0.332417	0.667583	28.111057	1.208242
25714.29	0.130000	0.870000	54.167013	0.300746	0.699254	25.432778	1.265563
27857.14	0.104000	0.896000	104.133657	0.272092	0.727908	23.009672	1.317422
30000.00	0.088000	0.912000	77.958573	0.246169	0.753831	20.817428	1.364340

Figure 6: Compressor System RBD Calculation Results

first case where it was 6,166 hours.

Figure 6 also shows an intermediate result at 8,760 hours (one year) of continuous operation. We can see that the system has not failed (0.6 expected failures) and has a further predicted availability of 0.66 (66%). Implementing the necessary preventive maintenance actions these indicators can be improved and the system can be much more stable.

B. Results Interpretation

Having obtained these results a reliability comparison has been made between the first case (prediction) and the RBD. This comparison is shown in Figure 7. Again, it can be seen the improvement obtained in the second case where the RBD has been modeled. These graphs come to strengthen the results presented so far.

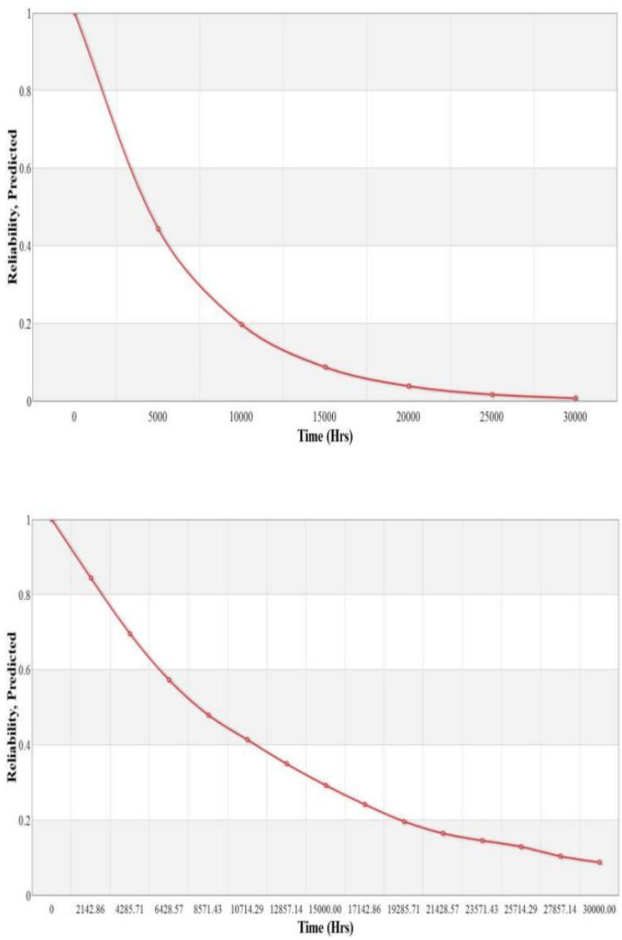


Figure 7: Reliability Comparison

Another important factor which further validates the results presented is the Availability of the system. This is represented in Figure 8 which again shows the relationship with the reliability.

This availability curve keeps the same line as the reliability curve presented in Figure 7. As the system runs continuously its performance drops and will need maintenance.

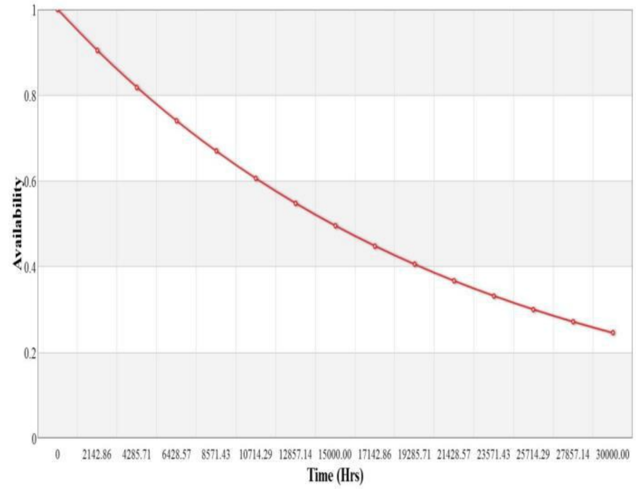


Figure 8: System Availability

Figure. 9 above shows the evolution of the number of failures as the system runs in time. It can be seen that for the period of 30,000 hours of operation the system has a low number of failure occurrence which gives stability.

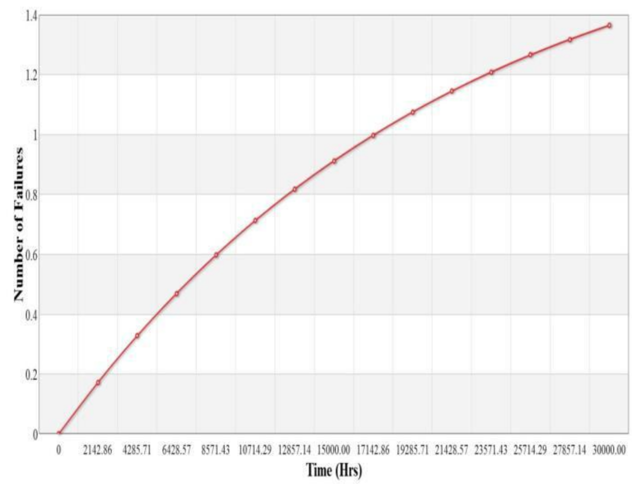


Figure 9: Expected Number of Failures

From this result Figure 10 further shows the distribution of the failures on the components of the system.

Again here we see that the air and oil filters have the largest distribution and will need regular checks and changes.

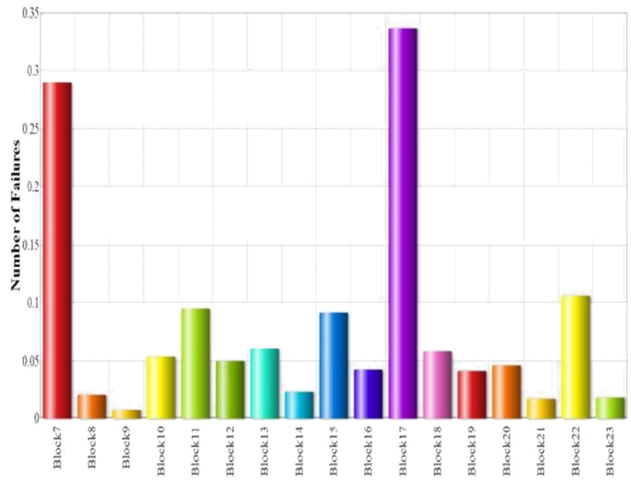


Figure 10: Failure Distribution to Components

4. CONCLUSION

The paper has presented a reliability approach on a compressor system using reliability block diagrams. The system has been modeled taking into consideration all its constituent components. This way the analysis has produced very giving conclusive results. The analysis has been made with the help of a software tool using widely accepted reliability standards.

The RBD model has shown great reliability improvements for the system in question giving stability to the system compared to the situation where only a prediction has been made. The results showed that the critical components of the system are the filters giving the fact that there are consumables and need to be checked and changed periodically.

Focus should be on the maintenance of the system, a good monitoring can eliminate unexpected failures thus maximizing the use of the system.

Further analysis can be made on the system considering the failure modes and the causes thus implementing a fault tree or failure mode and effect analysis.

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REFERENCES

[1] Natural Resources Canada, "Compressed Air, Energy Efficiency Reference Guide", 2007.

[2] R. F. Stapelberg, „Handbook of Reliability, Availability, Maintainability and Safety in Engineering Design", Springer, 2009.

[3] P. O'Connor amd A. Kleyner, "Practical Reliability Engineering, 5th Edition", Wiley Publication, 2011.

[4] ***PTC Windchill Quality Solusions – Reference Manual, 2013.

[5] Dan Iudean, Radu Munteanu jr., Florentina-Ancuta Cadar, Petru-Marius Maier, Alexandru Bogdan Amza, "Reliability calculus for an experimental device performing quantitative analysis of alcohol vapors from exhaled air", The 5th IEEE International Conference on E-Health and Bioengineering - EHB 2015, Grigore T. Popa University of Medicine and Pharmacy, Iaşi, Romania, November 19-21, 2015, ISBN 978-1-4673-7545-0/15/$31.00 ©2015 IEEE https://doi.org/10.1109/EHB.2015.7391388

[6] Dan Iudean, „Reliability Analysis through Block Diagram for Small Electric Motors", Acta Electrotehnica, Volume 56, Number 5, ISSN 2344-5637, ISSN-L 1841-3323 2015, Cluj-Napoca, Romania, pp. 241-244

[7] Hebedean Claudia, Munteanu Calin, Racasan Adina, Pacurar Claudia,"Parasiti Capacitance Removal with an Embedded Ground Layer", EUROCON 2013, Zagreb, Croatia, 1-4 Iulie 2013, pp.1863-1868, ISBN 978-1-4673-2232-4

[8] Grzegorz Kaczor, Stanisław Młynarski, Maciej Szkoda, "Verification of safety integrity level with the application of Monte Carlo simulation and reliability block diagrams", Journal of Loss Prevention in the Process Industries, Volume 41, May 2016, Pages 31–39, http://dx.doi.org/10.1016/j.jlp.2016.03.002

[9] Victor Vladareanu, Gabriela Tont, Luige Vladareanu, Florentin Smarandache, , "The navigation of mobile robots in non-stationary and non-structured environments", Inderscience Publishers, Int. J. Advanced Mechatronic Systems, Vol. 5, No. 4, 2013, pg.232- 243, ISSN online: 1756-8420, ISSN print: 1756-8412, Scopus (Elsevier),

[10] Vladareanu, V; Dumitrache, I; Vladareanu, L; Sacala, IS; Tont, G; Moisescu, MA, "Versatile Intelligent Portable Robot Control Platform Based on Cyber Physical Systems Principles", Studies In Informatics And Control, Volume: 24 Issue: 4 Pages: 409-418 Published: DEC 2015, WOS:000366543700005, ISSN: 1220-1766

[11] Fathollah Bistounia, Mohsen Jahanshahib, "Analyzing the reliability of shuffle-exchange networks using reliability block diagrams", Journal of Reliability Engineering & System Safety, Volume 132, December 2014, Pages97106, http://dx.doi.org/10.1016/j.ress.2014.07.012.