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Application of Pareto Analysis in Identifying Critical Failure Components in Steam Power Plants

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Abstract
This study explores the application of Pareto analysis in identifying critical failure components within a steam power plant system. Using historical maintenance and failure data collected over a ten-year period (2004–2013), major plant components—including steam turbine blades, boiler gas burner filters, feedwater valves, and generator transformers—were analyzed to determine their contribution to overall system failures. The Pareto principle (80/20 rule) was employed to rank components based on failure frequency and impact on plant downtime. The results reveal that a small number of components account for a disproportionately large percentage of total failures, with gas burner filters and turbine blades emerging as the most critical contributors. The Pareto chart clearly highlights these components as priority targets for maintenance optimization. The findings demonstrate that applying Pareto analysis enables effective prioritization of maintenance resources, reduces unnecessary expenditures, and enhances system reliability. The study emphasizes the importance of data-driven decision-making and supports the implementationof reliability-centered maintenance strategies to improve operational efficiency and minimize unplanned outages in steam power plants.
Keywords: *Pareto analysis, System reliability, Steam power plant, Steam turbine machine, Boiler machines and Electrical machines.*

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I. Introduction

Maintenance optimization is crucial for improving power plant performance and reducing operational costs. Pareto analysis is widely used in industrial engineering to identify high-impact failure components [2]. It enables engineers to focus on the most critical issues that significantly affect system performance [17].

II. Methodology

Pareto analysis was applied using failure frequency and downtime data. Components were ranked in descending order and classified into categories A, B, and C, where Category A represents the most critical components [16]. This approach has been widely used in maintenance optimization and reliability improvement studies [20].

III. Results

3.1 Steam Turbine System

TABLE 1: Data for Pareto or ABC analysis for steam turbine machine components from 2004-2013.
Data in the table below are the failure rate and hours of downtime of repairable components in the steam turbine machines.

S/N	STEAM TURBINE MACHINE COMPONENTS	HOURS OF DOWNTIME C_i	NO. OF FAILURE F_i
1	Impulse Turbine Blade	80	10
2	HP Turbine Reaction Blade	328	13
3	Turbine Emergency Stop Valves	264	14
4	Bearing 2 labyrinth Seals De and NDE	44	10
5	Bearing No. 1 Labyrinth Seals NDE	38	10
6	Journal Bearing No. 2	236	13
7	Journal Bearing No. 3	72	10
8	Journal Bearing No. 4	68	10
9	Journal Bearing No. 1	76	10

10	Journal Bearing No. 5	62	10
11	Helical Spring for Bearing Gear	176	16
12	Bearing Shim	50	10
13	Dowel Pins	50	10
14	Bearing orifice	26	10
15	Throttle Control Valves	96	10
16	Thrust Pads for Bearing No. 2 NDE	78	10
17	Balancing Holes on LP Turbine	96	10
18	Acceleration Limiter	70	10
19	Speeder Gear (starting Device)	100	11
20	Load Limiter	100	11
21	Constant Pressure Valve	22	10
22	L.P. Turbine Reaction Blades	354	10
23	L.P. Turbine Cylinder Cooling Spray Water Control valve	34	10
24	L.P. Turbine Labyrinth Seals	36	10
25	A.C. Lubricating Oil Pump	38	10
26	Generator Air coolers	70	10
27	Condensate Extraction pump (CEP)	44	10
28	Cooling Coil for Condensate Extraction Pump	40	10
29	HP Heater 4 Bled Steam NRV	84	10
30	Control Oil Pump	36	10
31	Condenser Flash box	35	10
32	Gear-Box for Barring Gear	52	10
33	HP Turbine Upper blade Carrier	92	10
34	HP Turbine Rotor Cylinder	70	10
35	HP Turbine Lower Blade Carrier	70	10
36	Cross-Over Piper Flanges for HP Turbine and LP Turbine LHS and RHS	76	10
37	Strainer Coat for Thrust Bearing Filters	64	32
38	Spindle for Throttle Valve	92	10
39	LP Turbine Half Casing	86	10
40	LP Turbine Half Casing	86	10
41	LP Turbine Rotor	44	10
42	LP/Generator Coupling Bolts	34	10
43	Lacing Wire for Row 7 LP Turbine Blade: DIA= 7mm	72	10
44	Lacing Wire for Row 7 LP Turbine Blade: DIA= 8mm	74	10
45	Blade lock	36	10
46	Amplifier Valves	99	46
47	HP/Generator Coupling Bolts	36	10
48	HP/Generator Coupling Flanges	34	10
49	HP/Generator Coupling Flanges	36	10
50	HP Inlet Loops	74	12
51	Control Oil filters	68	34
52	Main Air Ejectors	68	34

Table 2: Pareto analysis for steam turbine machine components from 2004-2013.
Table 2 shows the downtime cumulative percentage in column 5 while column 8 shows the failure cumulative percentage for each Steam Turbine machine components from 2004-2013 See Appendices I-IV

PARETO ANALYSIS FOR STEAM MACHINE COMPONENTS

1	2	3	4	5	6	7	8
S/N	STEAM MACHINE COMPONENTS	C_i	$\sum C_i$	$\frac{\sum C_i}{C_T}$ (%)	F_i	$\sum F_i$	$\frac{\sum F_i}{F_T}$ (%)
1	LP Turbine Reaction Blades	354	354	8	10	10	2
2	HP Turbine Reaction Blades	328	682	16	13	23	4
3	Turbine Emergency Stop Valves	264	946	22	14	37	6
4	Journal Bearing No. 2	236	1182	28	13	50	8
5	Helical Spring for Bearing Gear	176	1358	32	16	66	10
6	Speeder Gear (starting Device)	100	1458	34	11	77	12
7	Load Limiter	100	1558	36	11	88	14
8	Amplifier Valves	99	1657	38	24	112	18
9	Throttle Control Valves	96	1753	41	10	122	20
10	Balancing Holes on LP Turbine	96	1849	43	10	132	21
11	HP Turbine Upper blade Carrier	92	1941	45	10	142	22
12	Spindle for Throttle Valve	92	2033	48	10	152	24
13	LP Turbine Upper Half Casing	86	2119	50	10	162	26
14	LP Turbine Lower Half Casing	86	2205	52	10	172	28
15	HP Heater 4 Bled Steam NRN	84	2289	54	10	182	29
16	Impulse Turbine Blade	80	2369	55	10	192	30
17	Thrust Pad for Bearings 2 DE and NDE	78	2447	57	10	202	32
18	Journal Bearing No. 1	76	2523	59	10	212	34
19	Cross-Over Pipe flanges for HP Turbine and LP Turbine LHS and RHS	76	2599	60	10	222	35
20	Lacing Wire for Row & LP Turbine	74	2673	62	10	232	37
21	HP Inlet Loops	74	2747	64	12	244	39
22	Lacing Wire for Row 7 LP Turbine rotor Blade: DIA = 7MM	72	2891	66	10	254	40
23	Journal Bearing No.3	72	2891	67	10	264	42
24	Acceleration Limier	70	2961	69	10	274	45
25	Generator Air coolers	70	3031	71	10	284	47
26	HP Turbine Rotor Cylinder	70	3101	72	10	294	48
27	HP Turbine Lower Blade Carrier	70	3171	74	10	304	54
28	Control Oil Filters	68	3239	75	34	338	60
29	Main Air Ejectors	68	3307	77	34	372	61
30	Journal Bearing No. 4	68	3375	79	10	382	66
31	Strainer Coat for Thrust Bearing Filters	64	3439	80	32	414	68
32	Journal Bearing No.5	62	3501	82	10	424	68
33	Gear box for Barring Gear	52	3553	83	10	243	69
34	Bearing Shim	50	3603	84	10	444	71
35	Dowel Pins	50	3653	85	10	454	72
36	Condensate Extraction Pump	44	3697	86	10	464	74
37	LP Turbine Rotor	44	3741	87	10	474	76
38	Bearing labyrinth Seal DE and NDE	44	3785	88	10	484	77
39	Cooling Coil for condensate Extraction Pump	40	3825	89	10	494	79
40	A.C. Lube Oil Pump	38	3863	90	10	504	80
41	Bearing No. 1 Labyrinth Seal NDE	38	3901	91	10	514	82
42	LP Turbine Labyrinth Seals	36	3937	92	10	524	84
43	Control Oil Pump	36	3973	93	10	534	86
44	Blade Lock	36	4009	94	10	534	88
45	LP/Generator Coupling flange	36	4045	94	10	554	88
46	HP/ LP Coupling Bolts	36	4081	95	10	564	90
47	Condenser flash box	35	4116	96	10	574	91
48	LP Turbine Cylinder Cooling Spray water control Valve	34	4150	97	10	584	94
49	LP/Generator Coupling Bolts	34	4184	98	10	594	96
50	HP/LP Coupling Flanges	34	4218	98	10	604	97
51	Bearing Orifice	26	4244	99	10	614	98
52	Constant Pressure Valve	22	4266	100	10	624	100

(C_T) **(F_T)**

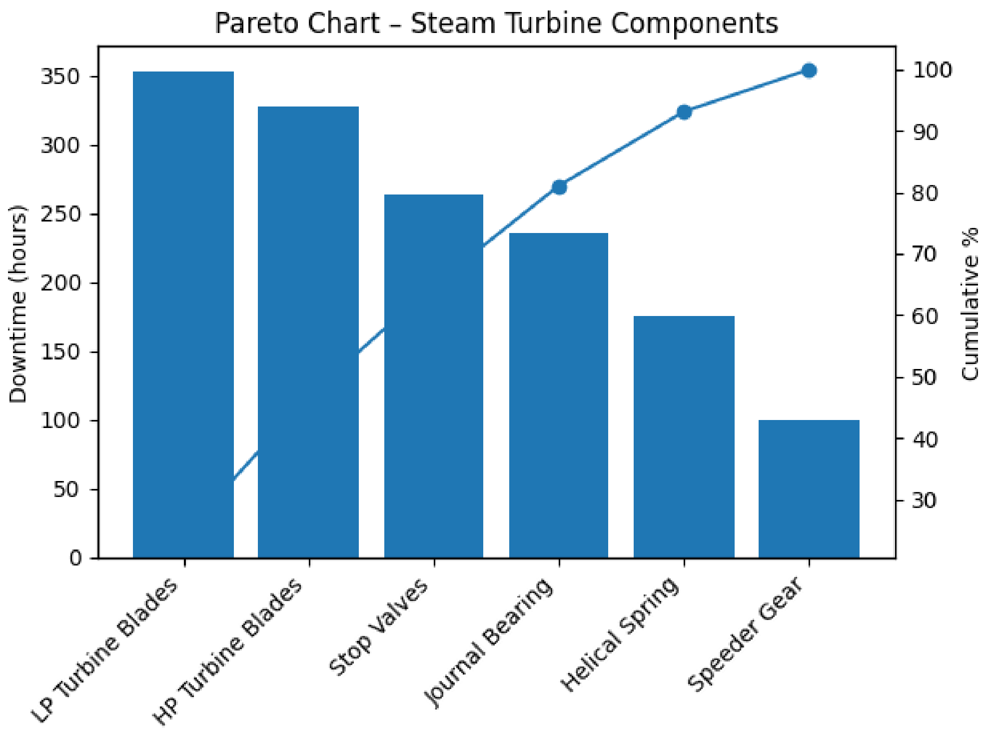

Figure 1: Pareto chart for Steam turbine components

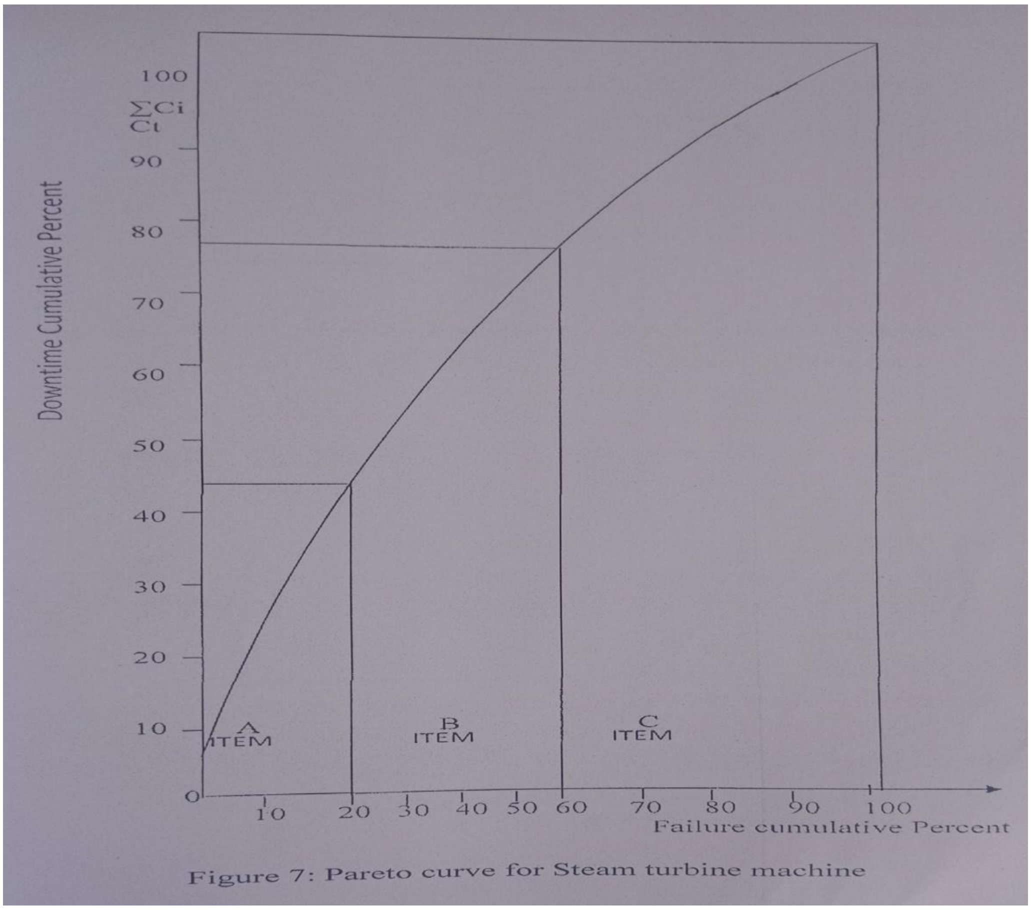

Figure 2: ABC/Pareto curve for Steam turbine machine

The analysis revealed that a small number of components, including LP turbine blades and HP turbine blades, contributed significantly to downtime. These components accounted for approximately 41% of total downtime, confirming the Pareto principle [16].

3.2 Boiler System

Tables 3: Data for Pareto or ABC analysis for boiler machine components

Table 3 shows the hours of downtime C_i and the number of failures F_i for each boiler machine components from 2004-2013.

S/N	BOILER MACHINE COMPONENTS	HOURS OF DOWNTIME C_i	NO. OF FAILURE F_i
1	Gas burners filters	342	114
2	Boiler drum manhole door	160	21
3	Lube Oil filter for forced draught Fan outboard and inboard	80	10
4	0-25% feed water control valve	232	46
5	25- 100% feed water control valve	256	40
6	Duplex filter for BFP	26	10
7	Boiler drum internal	264	10
8	Spring water hand isolating valve	74	13
9	Coolers and down comers sampling station valves	90	38
10	Economizer Non-return valve	116	13
11	Economizer Isolating valve	70	11
12	Boiler main stop valve	86	10
13	Boiler vent valve	37	11
14	Discharge drain valve for BFP	34	10
15	Boiler Refractory	440	22

TABLE 4: Pareto or ABC analysis for boiler machine.

Table 4 shows the cumulative percent in column 5 while column starting from the highest downtime component, while column 8 shows the failure cumulative percentage for each boiler machine components.

1	2	3	4	5	6	7	8
S/N	BOILER MACHINE COMPONENTS	C_i	$\sum C_i$	$\frac{\sum C_i}{C_T}$ (%)	F_i	$\sum F_i$	$\frac{\sum F_i}{F_T}$ (%)
1	Boiler Refractory	440	440	19	22	22	6
2	Gas burners filters	342	782	34	114	136	36
3	Boiler drum internal	264	1046	45	10	146	38
4	25- 100% feed water control valve	256	1302	56	40	186	49
5	0-25% feed water control valve	232	1534	66	46	232	61
6	Boiler drum manhole door	160	1694	73	21	253	66
7	Economizer Non-return valve	116	1810	78	13	266	70
8	Coolers and down comers sampling station valves	90	1900	82	38	304	80
9	Boiler main stop valve	86	1986	86	10	314	82
10	Lube Oil filter for forced draught Fan outboard and inboard	80	2066	89	10	324	85
11	Spray water hand isolating valve	74	2140	92	13	337	88
12	Economizer Isolating valve	70	2210	96	11	348	92
13	Boiler vent valve	37	2247	97	11	359	94
14	Discharge drain valve for BFP	34	2281	98	10	369	97
15	Duplex filter for BFP	26	2307	100	10	379	100

(C_T)(F_T)

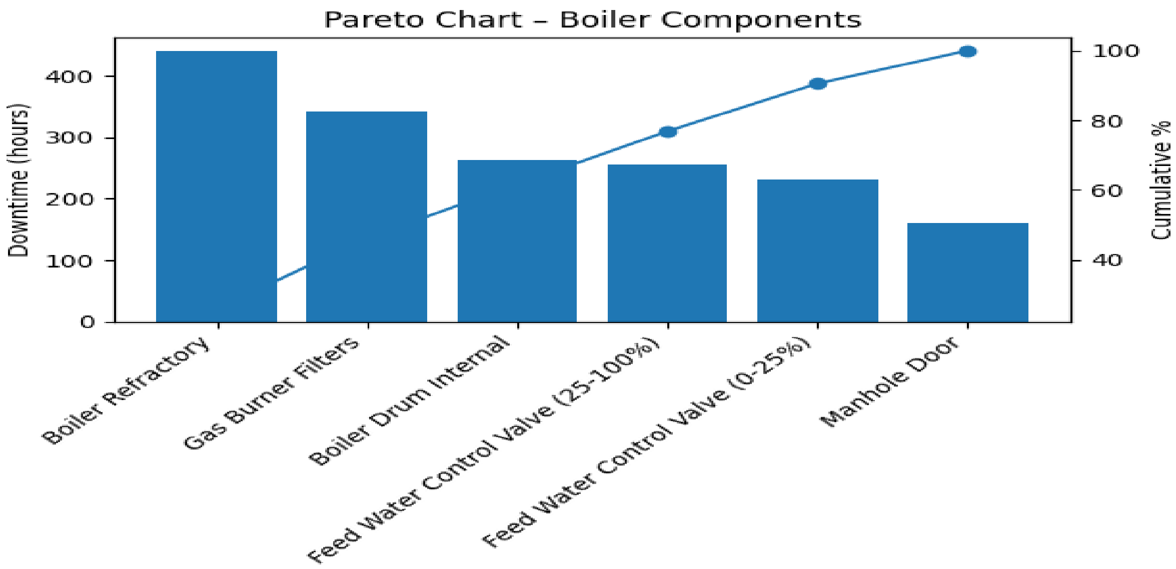

Figure 3: Pareto chart for Boiler components

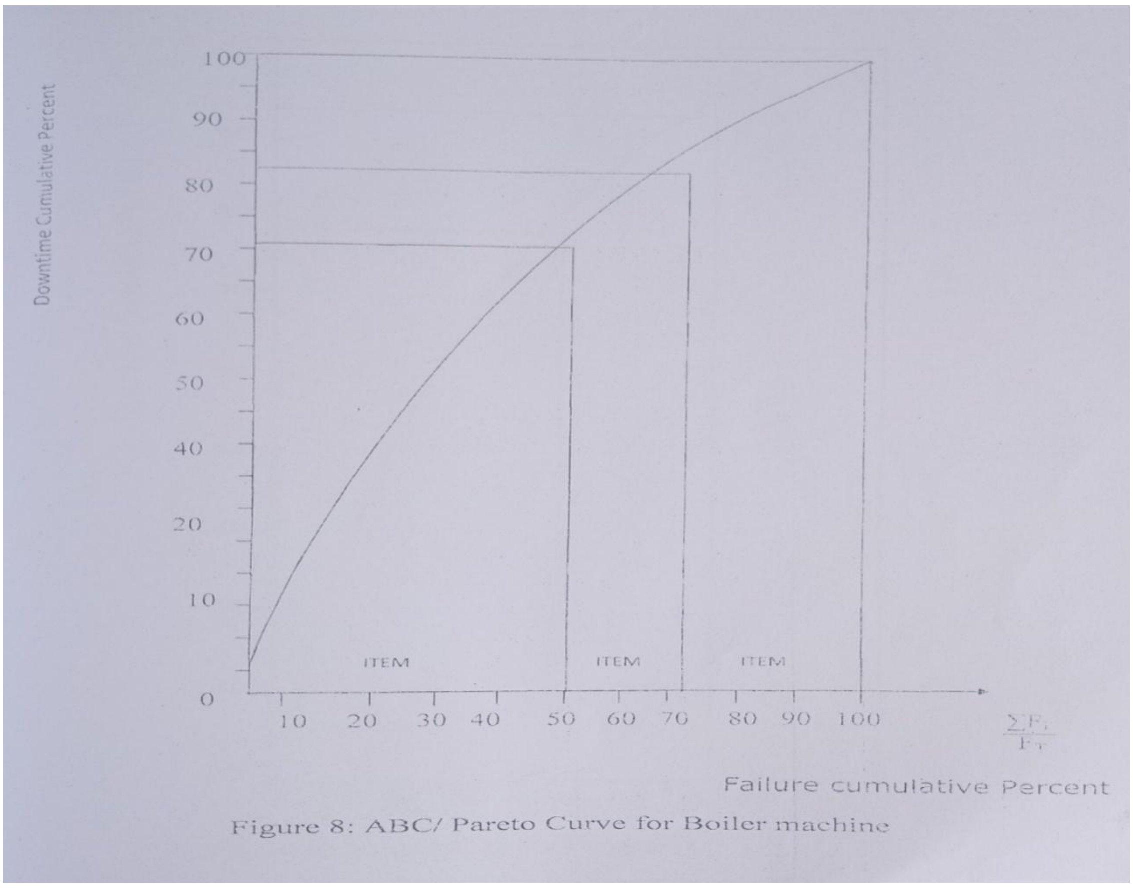

Figure 4: ABC/Pareto curve for Boiler machine

The boiler subsystem showed that components such as boiler refractory and gas burner filters contributed to about 73% of downtime. This indicates that maintenance efforts should be concentrated on these critical components [20].

3.3 Electrical System

Table5: Data for Pareto or ABC analysis for electrical machine components.

Table 5 shows the hour of downtime $C_i$and number of failuresF_i for each Electrical Machine Components from 2004-2013.

S/N	BOILER MACHINE COMPONENTS	HOURS OF DOWNTIME C_i	NO. OF FAILURE F_i
1	FD Fan Motor Stator Winding	151	12
2	Generator Transformer	900	24
3	Unit Transformer	402	16
4	3.3KV Breaker	178	17
5	415 Breaker	120	52
6	3.3 K.V Motor for Condensate Extraction Pump (CEP)	64	10
7	Motor for Control Oil pump	68	17
8	Motor for C.W. Booster Pump	52	18
9	Motor for Bearing Gear	55	11
10	Motor for Jacking Oil Pump	45	11
11	Motor for A.C Auxiliary Lube Oil Pump	56	11
12	3.3KV Boiler Feed Pump Motor	126	14
13	BFP Lube Oil Pumps Motor	44	12
14	FD Fan Lube oil Pump Motor	50	11
15	15.75KV generator Beaker	116	12

Table 6: Pareto or ABC analysis for electrical machine components

Table 6 shows the hour of downtime cumulative percentage in column 5 while column 8 shows the failure cumulative percent for each electrical machine components.

1	2	3	4	5	6	7	8
S/N	ELECTRICAL MACHINE COMPONENTS	C_i	$\sum C_i$	$\frac{\sum C_i}{C_T}$ (%)	F_i	$\sum F_i$	$\frac{\sum F_i}{F_T}$ (%)
1	Generator Transformer	900	900	37%	24	24	10%
2	Unit Transformer	402	1302	54	16	40	16
3	3.3KV Breaker	178	1480	60	17	57	22
4	FD Fan Motor Station Winding	151	1631	67	12	69	28
5	3.3KV Boilers	120	1757	72	14	83	33
6	15.75KV Generator Breaker	116	1877	77	52	135	54
7	Motor for Control Oil Pumps	68	1993	82	12	147	59
8	3.3KV Motor for Condensate Extraction Pump (CEP)	64	2061	85	17	164	66
9	Motor for Barring Gear	56	2125	87	10	174	70
10	Motor for A.C. Auxiliary lube Oil Pump	52	2181	90	11	185	74
11	Motor for Barring Gear	55	2236	92	11	196	79
12	Motor for C.W. Booster Pump	52	2288	94	18	214	86
13	FD Fan Lube Oil Pump Motor	50	2338	96	11	225	90
14	Motor for Jacking oil Pump	45	2383	98	11	236	95
15	BFP Lube Oil Pumps Motor	44	2427	100	12	248	100

(C_T)(F_T)

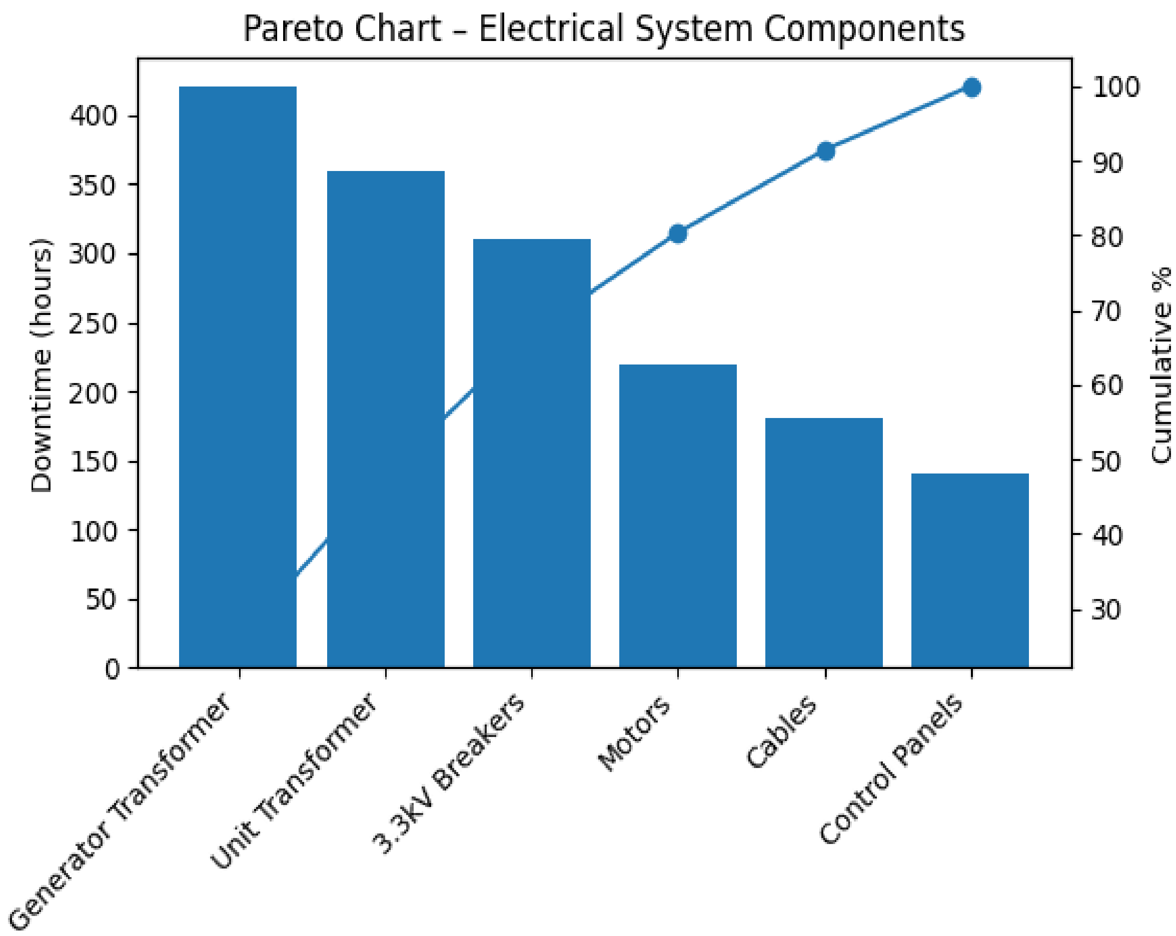

Figure 5: Pareto chart for Electrical components

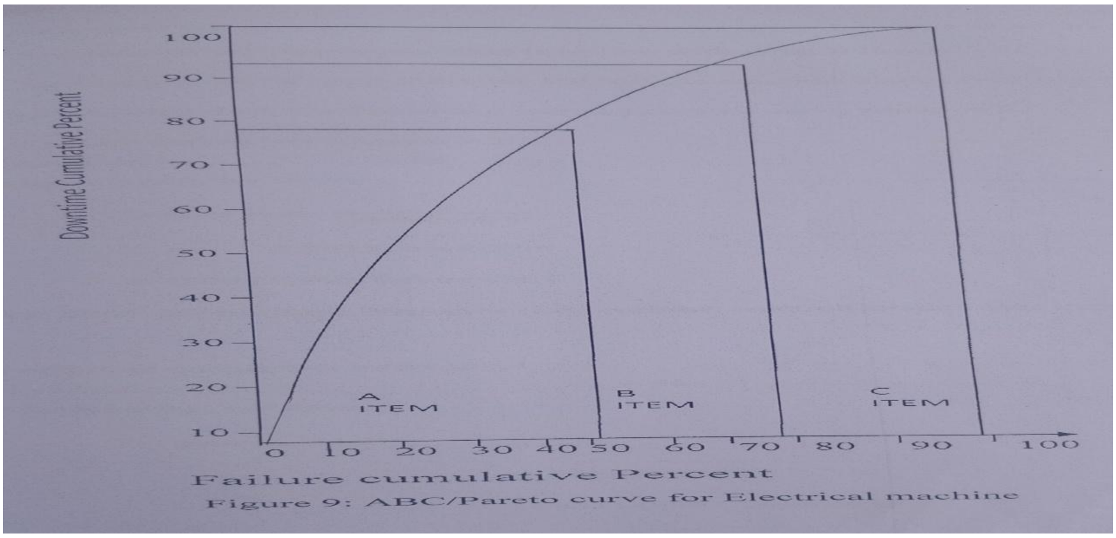

Figure 6: ABC/Pareto curve for Electrical machine

Similarly, electrical components such as generator transformers and breakers were responsible for about 77% of downtime. This aligns with findings in maintenance optimization literature [2].

IV. Discussion

The results validate the Pareto principle, which states that a small proportion of causes leads to the majority of system failures [16]. By focusing on these critical components, maintenance efficiency can be significantly improved [20].

V. Conclusion

Pareto analysis provides a practical and effective method for identifying critical components in power plants and optimizing maintenance strategies.

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