THE 21ST INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

OMAINTEC 2024 CONFERENCE EXHIBITION

Implementing RCM Model for a Power Distribution System: A Case Study in Saudi Arabia

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#OmaintecConf

An Initiative by OMAINTEC المجلس العربي للتشغيل والصيانة Arab Operations & Maintenance Council

Organized by EXICON International Group مجموعة أكزيكون الدولية

Introduction

Background

01 Time-based PM has little effects on reliability

02 Complex systems have non-time-related failure model

03 RCM utilizes maintenance tactics

04 Applied at equipment level, system level, & program level

RCM

01 Initiated in aviation industry in early 60s

02 Developed to alleviate maintenance burden

03 e.g. Boeing reduced labor hours from 4 M to 66 k; 7 major overhauls versus 339

04 Employed in power system in 80s

Methodology

Methodology — Pre-analysis — Main analysis — Post -analysis

Formulation

Data collection

Numerical analysis

Methodology

Methodology — Pre-analysis — Main analysis — Post -analysis

Critical equipment identification

Identify current failure rate

Identify critical equipment

Identify brand -new equipment failure rate

$$CF'm,j > \mu CFm,des > 1$$

$$CFm,j = \alpha \frac{\Delta\lambda m,j}{\lambda m1} + \beta \frac{\Delta Um,j}{Um1} + \gamma \frac{\Delta EENSm,j}{EENSm1}$$

Methodology

Methodology

Pre-analysis | Main analysis | Post -analysis

Failure rate modeling

Historical records

Inspection -based condition ranking

Mathematical interrelation

$$x_t^k = 1 - \frac{x_t^k(cs) - x_0^k}{x_1^k - x_0^k} = \frac{x_1^k - x_t^k(cs)}{x_1^k - x_0^k}$$

$$\lambda(x) = Ae^{Bx} + C$$

Methodology

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Methodology

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Failure rate modeling

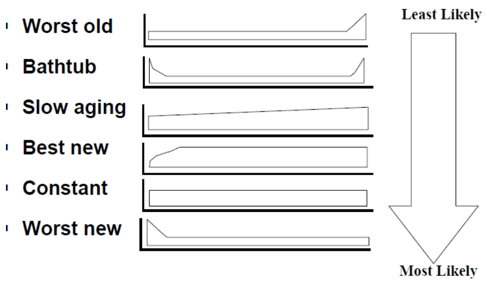
$$\lambda(x) = Ae^{Bx} + C$$

$$A = \frac{[\lambda(0.5) - \lambda(0)]^2}{\lambda(1) - 2\lambda(0.5) + \lambda(0)}$$

$$B = 2\ln\left(\frac{\lambda(0.5) + A - \lambda(0)}{A}\right)$$

$$C = \lambda(0) - A.$$

BCR and update load point failure rate.



Find failure rate

Form weighing table for each critical equipment

Evaluate load point failure rate

$$X_t^k = 1 - \frac{X_t^k(cs) - X_0^k}{X_1^k - X_0^k} = \frac{X_1^k - X_t^k(cs)}{X_1^k - X_0^k}$$

Inspection Item	Weight (W)	Score (S)
Corrosion	3	0.5
Gaskets failure	3	0.8
Loose bolts, connections	7	0.75
Over pressurization	7	0.5
Porcelain failure	2	0.8
Seal failure	2	0.8
Valve leak	4	0.8
Weld failure	2	0.6
Bushing failure	3	0.75
Insulation failure	4	0.75
Oil contamination	6	0.65
Low oil	4	0.75
Solid insulation failure	4	0.7
Winding insulation failure	5	0.57
Oil dielectric failure	6	0.65
Tap changer failure	5	0.7
High resistance load path	3	0.75
Open circuit	3	0.8
Out of calibration	3	0.6
Shorted turns	4	0.8
Sum	$\sum_{i=1}^{c} W_i = 80$	$\sum_{i=1}^{c} W_i S_i = 55.125$
Weighted Average	$X_t^k(cs) = \sum_{i=1}^{c} W_i S_i \Big/ \sum_{i=1}^{c} W_i = 0.69042$	

Methodology

Methodology

Pre-analysis | Main analysis | Post -analysis

Cost -benefit analysis

PM cost

CM cost

BCR

$$Ncm = \frac{tpm}{MTTF} + 1.$$

Case Study

Case Study

- Substation resides in Saudi Arabia.
- Power system feeds utility, academic, commercial, & residential loads
- Two incomers coming from utility 13.8 kV
- Open -loop configuration
- RCM applied to medium voltage system
- Low voltage equipment at premises of MV & LV

Pre-Analysis

Methodology

Pre-analysis

01

Single-line diagram

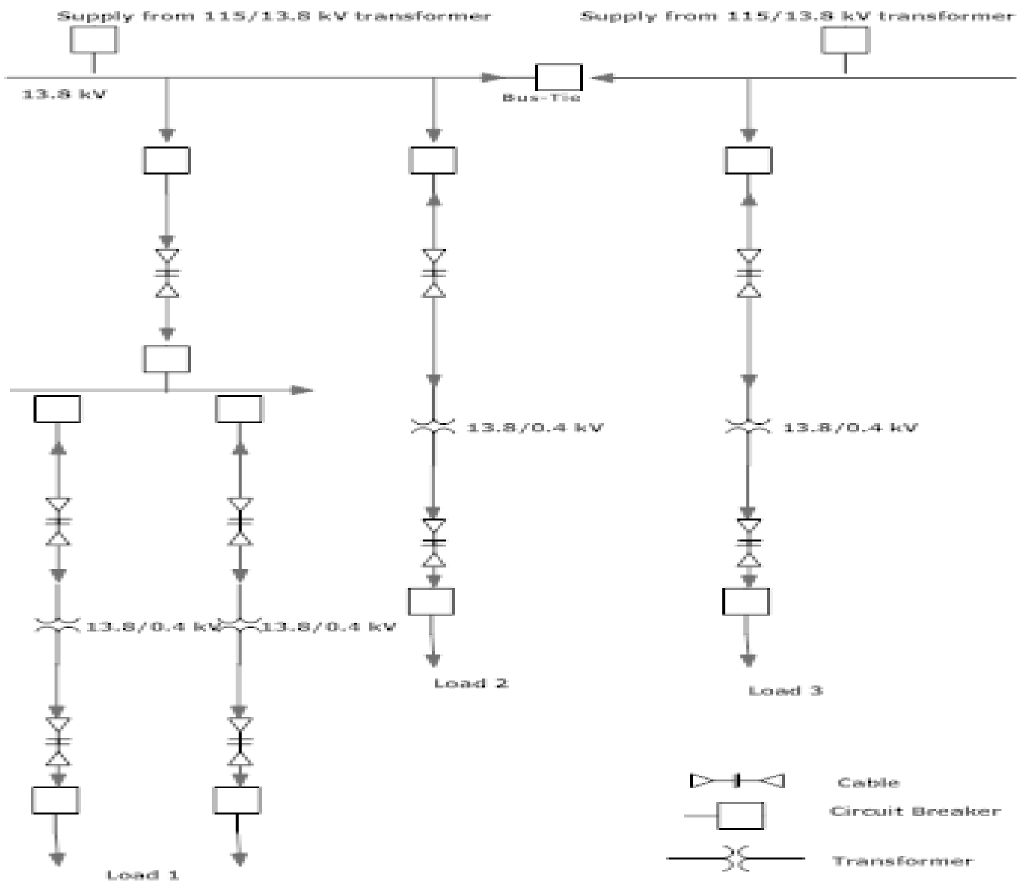
Pre-Analysis

Methodology

Pre-analysis

01

Single-line diagram



Pre-Analysis

Methodology

Pre-analysis

02

Data requirements

Pre-Analysis

Methodology

Pre-analysis

03

System boundary identification

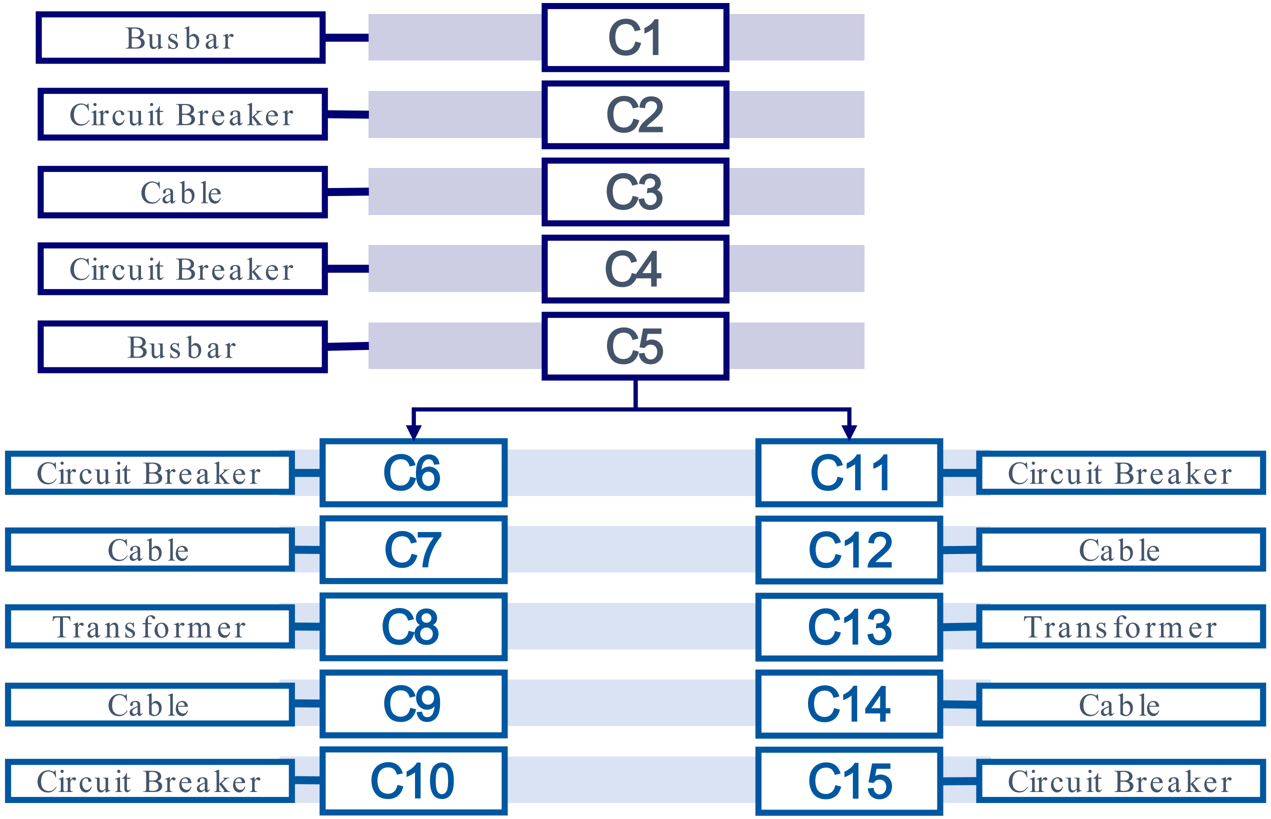
Pre-Analysis

Methodology

Pre-analysis

03

System boundary identification



Pre-Analysis

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Pre-analysis

04

Component -type selection for analysis

Pre-Analysis

Methodology

Pre-analysis

05

System reliability target

Pre-Analysis

Methodology

Pre-analysis

05

System reliability target

Reliability Indices	$\lambda_{Load1.Des.}$ (Occ./Yr.)	$U_{Load1.Des.}$ (hr./Yr.)
Target Value	0.8	1.5

Pre-Analysis Summary

Methodology

Pre-analysis

- Single-line diagram
- Data requirements
- System boundary identification
- Component -type selection for analysis
- System reliability target

Main Analysis

Methodology

Pre-analysis

Main analysis

01

⚠ Critical component identification

Main Analysis

Methodology

Pre-analysis

Main analysis

01

Critical component identification

Scenario	Scenario 1			Scenario 2		
Equipment	λ	R	u	λ	R	u
C1	0.01	1	0.01	0.01	1	0.01
C2	0.09	2	0.18	0.09	2	0.18
C3	0.024	6	0.15	0.024	6	0.15
C4	0.09	2	0.18	0.09	2	0.18
C5	0.01	1	0.01	0.01	1	0.01
Ceq	0.79	2.2	1.75	0.72		1.66
Indices	1.0168		2.27	0.94		2.18

$$CFm,j = 3\frac{\Delta\lambda m,j}{\lambda m1} + 4\frac{\Delta Um,j}{Um1} + 0\frac{\Delta EENSm,j}{EENSm1}$$

Main Analysis

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01

Equipment Criticality Factor

Critical component identification

Components	$\lambda^2_{Load\ 1}$	$U^2_{Load\ 1}$	$EENS^2_{Load\ 1}$	Criticality Factor	CF
C8	0.94	2.18	-	0.5	0.5
C13	0.94	2.18	-	0.5	0.996
C9	0.83	2.28	-	0.18	1.2
C14	0.83	2.28	-	0.18	1.4
C2	0.997	2.234	-	0.1	1.4
C4	0.997	2.234	-	0.1	1.5
C7	0.987	2.28	-	0.06	1.56
C12	0.987	2.28	-	0.06	1.6
C10	0.98	2.25	-	0.05	1.7
C15	0.98	2.25	-	0.052	1.7
C3	1.01	2.24	-	0.051	1.78
C6	1.009	2.25	-	0.05	1.8
C11	1.009	2.25	-	0.05	1.88
C1	1.02	2.27	-	0.03	1.95
C5	1.02	2.27	-	0.03	1.95

$$CF'm,j > 1.6CFm,des = 1.3$$

Main Analysis

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Failure mode detection

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02

Failure mode detection

Equipment	Failure Modes	Failure Causes	
Power Transformers C8 & C13	External leakage	• Porcelain failure • Corrosion • Loose connections Valve leak	• Weld failure • Over pressurization • Gasket failure
	Deteriorated insulation	• Low oil level • Insulation failure • Tap changer failure • Solid insulation failure	• Winding insulation failure • Oil dielectric failure • Bushing failure • Oil: contamination/degradation
	False output Reading/No output	• Shorted winding turns • Open circuit • High impedance load path • Out of calibration • Auxiliary control failure	• Radiator: clogged/corroded • Fan failure • Pump failure • Restricted oil flow • Bushing CT failure

Main Analysis

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Failure rate modeling

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Failure rate modeling

Components	X_t^k	λ
Transformer C8	0.59	1.86
Transformer C13	0.61	1.97
Cable C9	0.67	1.88
Cable C14	0.68	1.99

$$\lambda(X_t^k) = 0.05165e^{2.2478602x} - 0.008148148$$

Main Analysis

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Main analysis

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Load point reliability assessment

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04

Load point reliability assessment

λ (Occ./Yr.)	U (hr./Yr.)
0.918	2.248

$\lambda_{(desired)}$ (Occ./Yr.)	$U_{(desired)}$ (hr./Yr.)
0.8	1.5

Main Analysis

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Outline possible maintenance strategies

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Main Analysis

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05

Outline possible maintenance strategies

Plan	Maintenance Tactic
Plan 1	Oil-level test; gasket & oil sampling valve; oil contamination & dielectric failure analyses; oil conservator assessment
Plan 2	Valve leak & weld failure checkups; seal failure & paper sample inspection; solid insulation inspection
Plan 3	Corrosion inspection; calibration checkup; high impedance load path test
Plan 4	Loose connections inspection; over pressurization test; short circuit voltage analysis; no-load current & losses
Plan 5	Buchholz relay inspection; pressure relief device, indicators, control circuits, and winding resistance analysis; protection analysis
Plan 6	Inspection of bushings, oil level & gasket, surge arrestors & bushings connections inspection
Plan 7	Tap changer inspection; dehydrating breather assessment; motor drive condition inspection; contacts & leads insulation of tap changer connections & leads inspection
Plan 8	Radiator, coolers, fans, and pumps inspection

Main Analysis

Methodology

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Main analysis

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Benefit -to -cost analysis

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Main Analysis

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Main analysis

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Benefit -to -cost analysis

Maintenance Plan	Maintenance Costs				Maintenance Benefits		BCR
	$C_{pm,i}{}^{m}$	$C_{pm,i}{}^{t}$	$C_{pm,i}{}^{I}$	$\sum Cost$	N	Benefit	
Plan 1	1,000	10,000	12.5	11,012.5	2.3	25,695.83	2.33
Plan 2	1,000	60,000	50	61,050	2.18	132,873.5	2.18
Plan 3	1,000	20,000	25	21,025	2	42,050	2.0
Plan 4	1,500	1,000	12.5	2,512.5	1.83	4,606.25	1.83
Plan 5	1,900	1,000	25	2,925	1.77	5,175	1.77
Plan 6	1,300	20,000	37.5	21,337.5	1.67	35,562.5	1.67
Plan 7	1,800	21,000	62.5	22,862.5	1.71	39,192.86	1.71
Plan 8	1,800	1,000	12.5	2,812.5	1.71	4,821.43	1.71

Main Analysis

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Main analysis

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Optimal maintenance strategy selection

Main Analysis

Methodology

Pre-analysis

Main analysis

07

Optimal maintenance strategy selection

Calculate reliability indices

λ (Occ./Yr.)	U (hr./Yr.)
0.810749	1.561864

Main Analysis Summary

Methodology

- Pre-analysis
- **Main analysis**

- Critical component identification
- Failure mode detection
- Failure rate modeling
- Load point reliability assessment
- Outline possible maintenance strategies
- Benefit -to -cost analysis
- Optimal maintenance strategy selection

Post -Analysis Summary

Methodology

- Pre-analysis
- Main analysis
- **Post -analysis**

Record reliability data

Document progress

Use knowledge management tools

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Summary

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Post-analysis

Formulation

- Data collection
- Numerical analysis

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Failure rate modeling

- Historical records
- Inspection -based condition ranking
- Mathematical interrelation

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THANK YOU!

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