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METHOD FOR SELECTION CONDITION MONITORING TECHNIQUE OF INDUCTION MOTOR – LOAD SET USING MCDM FOR FEASIBLE INDUSTRIALAPPLICATION

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ABSTRACT

Induction Motor is very widely used machine in industries, because of its variousadvantages like robust design, less frequency of maintenance and low maintenance cost, easy speed control and starting method, high efficiency and obviously low cost then dc machine. Today IM consume nearly 35%-40% of total electrical energy used in industries worldwide. Where IM mainly works as a driver machine, which drive loads such as compressor & pump mostly. Hence to keep in mind asset maintenance, reduce down timeas well as prevent break down, increase life cycle of IM-Load set maintenance engineer has developed many Condition monitoring technique. But selection of proper technique or methods is very importance economically technology, which will provide proper Return of Investment. This paper approach towards a selection of proper method of CMtechnique of induction motor – load set depending of every possible parameters like seriousness of fault effect, cost of implementation, simplicity of data collection, system criticality, noise effect. Each method of CM technique efficiency has been understand properly by literature survey of various research done till now as well as survey done on effectiveness of industrial application of various CM technology. A serious score and weightage of each score has been dedicated for various CM technology depending on various parameters of Motor or Load. Then a mathematical tool Multi criteria Decision-Making (MCDM) use to find best technology comparing various combination dependingscore, weightage and servility of each parameters.

KEYWORDS: Condition Monitoring, Asset Maintenance, Down Time, Break Down, Life Cycle of Machine, MCDM.

1. INTRODUCTION

In the recent year, Condition Based Maintenance has reached great standard thanks to its universal acceptance as the most cost-effective method for asset maintenance and probably increase life cycle of machine. The name condition monitoring clearly define that the maintenance task performed based on the real time condition of the machine, the real time data may be collected by automatically using various sensors and transducers or by manually using proper instrument. It has observed across the industries that 3-phase Induction motor which is also known as 3-phase asynchronous motor has vast application for its various advantages, andalmost 45% of total electrical energy used by IM is application for driver of Pumping system, mostly centrifugal pump (Resa et al., 2019), (Stopa et al., 2014). Hence, for the huge industrial application of IM-Pump set, motto of this paper is to find proper investment toward suitable technology so that maximum return of investment can get. This research paper address various faults occur at IM-Pump set maximum time, also put in eye about other application of IM and various load like compressor, Fans, Conveyors. Numerous parameters which are like problematic to implementing the solution were well- thought-out. As per the statistical data, approximately 30% of the production cost of any product waste forbreakdown, where 13.3% break down time losses are planned production time which then include as hourly down time cost. Where unplanned down time is much higher than planned down time, this unplanned break down time only cost money, it also increase lead time, reduceconsumer trust and also effect quality of production (Elliot, 2015). Table1 shows some data ofbreak down time cost suffered across the industries.

Table 1. Downtime cost across some industries (https://Behrtech.Com/Blog/Infographic-20-Mind-BogglingStats-on-Cost-of-Industrial-Downtime/, n.d.)

Industries	Losses
Process Industries	Industries 5% of total output value loss due to unplanned downtime
Automobile	22000 USD lost every minute of downtime
Oil & Gas	38 million USD of financial loss due to unplanned downtime annually

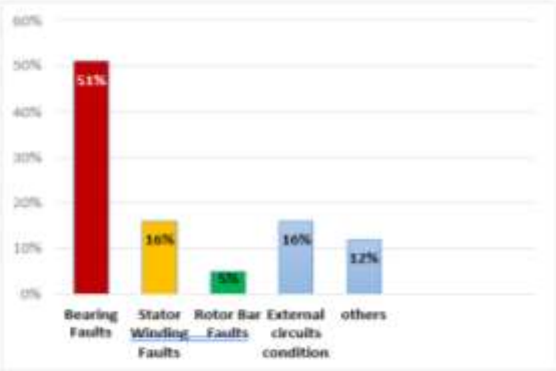

Figure 1. Failure distribution in common loads connected to IM (Terron-Santiago et al.,2021), (Goman et al., 2019).

It has been observed by the historical data of machines that a complete breakdown is not happened suddenly, but gradual degradation of any or several parts of machine causes massivebreakdown of the machine. Overlook of such slow degradation of machine not only result breakdown, also it reduce efficiency of the machine, consume more energy, and that means it reduce total quality of the production. Faults in such machine occur mainly due improper maintenance, improper installation and aging of few parts. According to IE rule, it has been clearly stated that how preventive or routine maintenance of IM should be done.

According to the historical data figure 2 shows the probability of parts of IM

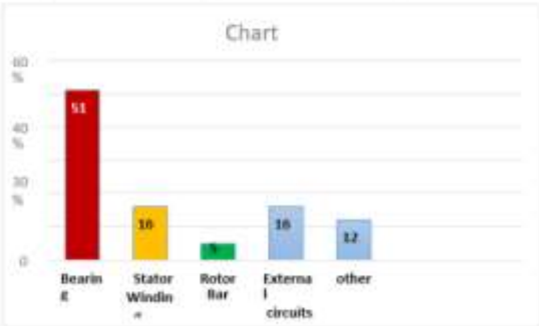

Figure 2: Parts failure probability distribution in IM

To decrease down time cost, we have reducing number of break down. Hence break down can be reduced by continuous or periodical condition monitoring of IM which in results provide data for health or condition of each parts of IM as well load like Pump. To catch the faults at emerging level, condition monitor techniques can be implement for IM-Pump set are Vibration Monitoring, Current Monitoring, Thermography monitoring, Flux Monitoring, Acoustic Monitoring.

There are two approaches in which CM are be applied,

Online- Applied when the machine is in working condition (e.g., vibration monitoring, current monitoring, and thermography, flux)

Offline- Applied when the machine is not working (e.g., checking misalignment, bending of shaft)

Collection of data may be done continuously and periodically, mostly where the system is precious i.e. means high cost or associated with very important process, data of condition collected continuously and atomically with the help of sensor and transduce to reduce risk of break down.

Hence, we can understand that implementation of this process is also costly as well as proper selection of CM technique is also necessary same, so this paper will show as which CM technique will be more justified and beneficial for industries.

Generally periodic data collection method is applied to new machine as well as where prevention of breakdown will lead to maximize profit on investment (Laws and Muszynska, 1987).Section 2 of this paper give a brief description of each technique of CM and section 3 is the main part where method for selection of condition monitoring technique of induction motor –load set using MCDM based on significant parameter for real time industrial application. At section 4 draw a conclusion depending on the final score of MCDM which is the finding of this paper.

2. CONDITION MONITORING TECHNIQUE

Here in this section, various technique of Condition Monitoring will be elucidate. Efficient CMtechniques are Vibration

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Monitoring, Motor Current Monitoring, Flux Monitoring, Thermography Monitoring, and Acoustic Monitoring.

2.1 Vibration Monitoring:

Every dynamic machine as its own permissible range of vibration which is specified at ISO: 10816-6 1995, shown in fig 3. Additional vibration means there is a problem in the machine. Vibration signal is a very useful technique to detect mechanical faults at primary level like baring fault, misalignment, cavitation, gear fault, eccentricity and imbalance (Han and Song, 2003). Vibration of machine also increase due to uneven air gap, stator winding problem, asymmetrical power supply fault hence there is also possibility of detecting such electrical faults using Vibration Monitoring.

Data of Vibration usually collect using accelerometer, which measure vibration three axis wiseor radial wise (Yu, 2020).Depending on the position of sensor placed on the machine accuracy,precision of the data increase and also able to find different type of faults.

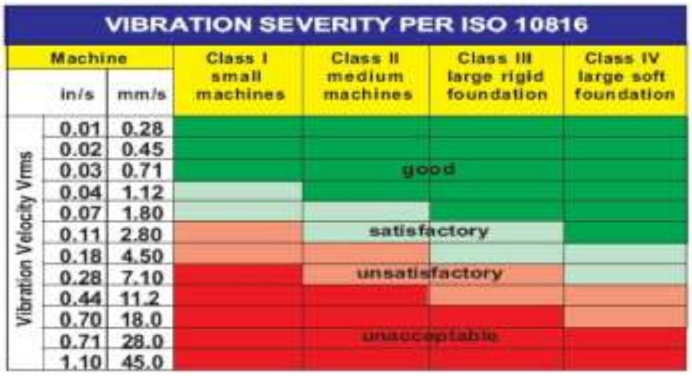

Fig 3: Vibration Analysis of Various class of Machine.

2.2 Motor Current Monitoring:

It is an import and cost efficient tool for detecting electrical faults like Stator winding and RotorBar faults of IM, Data collection of Motor current is very easy and independence of back ground noise hence chances of getting noise free data is more.

Due mechanical stress, overheating and moisture insulation of stator may degrade, which inresult short circuit and generate more heat consequently more degradation of insulation and

more damage in the field winding. Motor current analysis will detect such fault at primary leveland save industries from huge asset loss, prevent from fire accident.

If any rotor bar gets damage, then asymmetrical magmatic field will flow which result backward rotating field at the slip frequency respective to the forward rotating rotor, due to thisbackward rotating field concerning the rotor induces electromagnetic force and current in statorwinding (Mehala & Dahiya, 2007). This fault also can detect by using Motor Current analysisat an early state.

Motor Current Monitoring is also shows its excellence in detecting mechanical faults like Eccentricity faults, bearing faults and Gear box fault efficiently.

2.3 Flux Monitoring

Flux monitoring is based on the leakage or stray flux density of a motor, this technique is verymuch capable of detecting squirrel cage rotor's cage or bar fault with proper accuracy. Field winding fault, dynamic eccentricity faults can also be detected using Flux monitoring.

2.4 Thermography Monitoring

Abnormal temperature distribution throughout the machine body is one of the most common indicator for faulty machine or faults corroded electrical connection, short circuit in the windings, increase bearing friction, lack of lubrication. Hence Temperature analysis with the help of Infrared thermography (IRT) and Forward Looking Infrared (FLIR) camera is very efficient CM technique, but this technique is very sophisticate and chance of getting less accurate data is more because of background or ambient temperature effect.

Expression for Comparison are done on the relative temperatures ΔT

$\Delta T = T(local) - T(ambient)$ .... eq 1

2.5 Acoustic Monitoring

Noise and Vibration of a machine provide many important information about its internal condition. Noise analysis or Acoustic Monitoring is low cost but highly efficient technique, microphone use as a transducer to collect noise of a machine, but there is chance of mixing background noise is very common, but with help of software it can be

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eliminated easily. Acoustic Monitoring is very good technique for detecting broken rotor, broken cage of bearing, but accuracy of detecting electrical fault is very good.

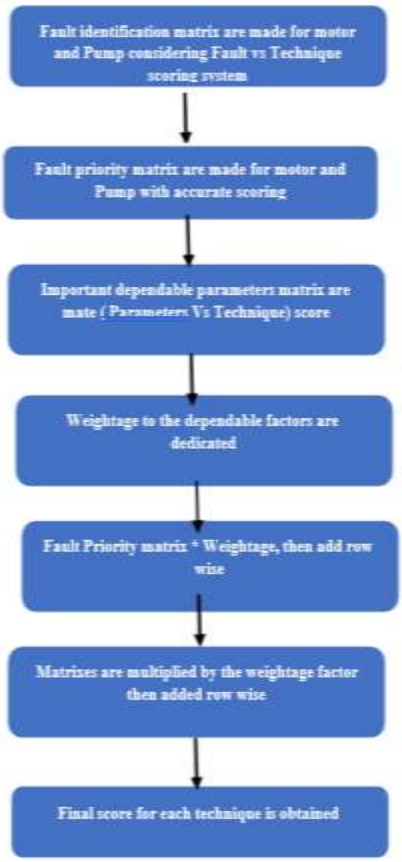
3. METHOD SELECTION OF CONDITION MONITORING

For perfect assessment of CM here both Motor as well as Pump (Load) is consider. Every technique of CM has its distinctiveness and capability to catch fault from primary stage. Moto of this paper is to find the best technique or combination of technique. The result will be reliable and most efficient to catch faults, economical so that it will be perfect for industrial application.Hence to do so various parameters associated with practical application for individual technique is concern which chief acceptance in Industries.

For making an optimal choice, comparing multiple criteria MCMD is the best tool, there are some other tools like AHP, TOPSIS, PROMETHEE, PSI, VIKOR which also can be used instead of MCDM, but in-terms of precision and simplicity MCDM is the best among them.

The proposed model is based on WEIGHTED SUM MODEL of MCDM with an additionaljustification factor for fault categories.

Part I - The proposed flowchart for finding the CM technique ranking methodology perindustrial factor is shown below in Figure 4



Part II- The proposed model/ flow chart for the best technique combination includingindustrial application parameters and different system required is shown in figure 6

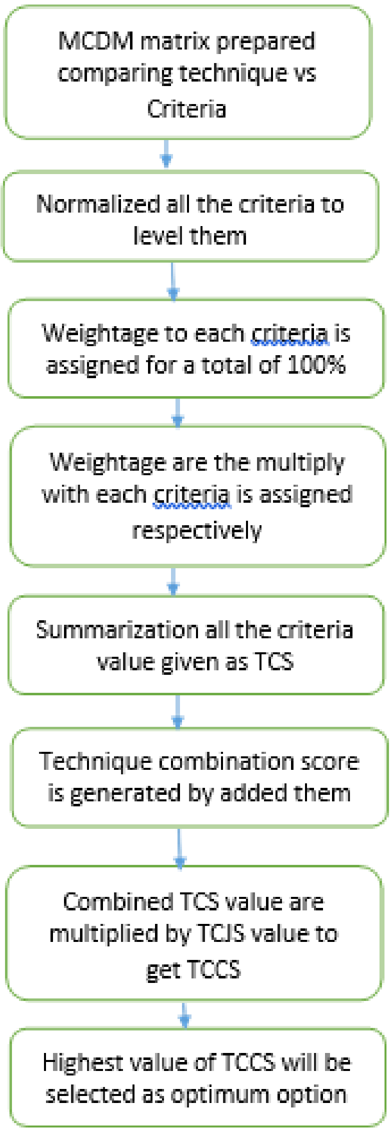
Here **Technique Credit Score (TCS)** is obtained by which contain the final score of each parameter when applied independently to detect fault.

Technique Combination Justified Score (TCJS) states us that which combination of technique is bestfor detecting electrical as well as mechanical fault.

Technique Combination Credit Score (TCCS) is combination score each individual technique TCS.

TCCS = [TCS1 + TCS2..................TCSn] * NTCJS eq2

Here NTCJS is Normalization of TCJS, Normalization is done to improve reliability of the database.



technique of IM) and Matrix B (Score matrix for various CM technique of most common load i.e. Pump) is built considering various important, critical parameters, and the score is dedicated to eachtechnique depending details study of past research papers.

(Djeddi et al., 2007; Kanovic et al., 2013; Gugaliya et al., 2018; Mehala & Dahiya, 2007; Ye & Wu, 2000; Jin et al., 2016; Glowacz & Glowacz, 2017; Glowacz, 2018; Vitek et al., 2011; Goktas et al., 2017).

Table 02: Shows severity valuation of each critical and most happening faults

Faults Type	FAULT LEVELFAULT	PrimaryLevel	IntermediateLevel	Severe Level
MechanicalFaults	Bearing Faults	Fine single crack	Many crack, Pitting	Roughness, Broken race
	Cavitation	Light popping noise	Periodical cracking noise	Steady rumbling noise
	Gear Faults	Surface pitting	Low wear	High wear
	Eccentricity	< 3mm	<4mm	<5mm
	Misalignment	<4mm offset	<5mm offset	<7mm offset
ElectricalFaults	Stator winding faults	1-3 turns short	6-8 turns short	High turns short
	Broken Rotor Faults	1 broken bar, crack in bar	2-3 broken bar	Multiple broken bar

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Proposed Score for matrix A (IM) matrix B (Pump)

Score for each technique are proposed based on fault detection capability, Table XX shows severity valuation of each critical and most happening faults, Table V and Table 6 show proposed score for each technique. The score are describe below.

0: Technique is not able to detect the fault

1: Technique can detect fault at the severe level 2: Technique can detect fault at intermediate level 3: Technique can detect fault at primary level **Abbreviation of faults:**

BRG : Bearing Faults

SWD : Stator Winding FaultsRBB : Rotor Bar Broken CVF : Cavitation Fault

GDF : Gear Defect FaultECC : Eccentricity

MIA : Misalignment

Table 3: Proposed score for each fault detection Technique (Motor side)

MATRIX A				
TECHNIQUE	**BRG**	**SWD**	**RBB**	**MOTOR SIDE (IM)**
Vibration	**3**	**2**	**1**	
Motor Current	**1**	**3**	**3**	
Thermography	**2**	**2**	**2**	
Flux	**0**	**3**	**2**	
Acoustic	**1**	**0**	**1**	

Table 4: Proposed score for each fault detection Technique (Pump Side)

TECHNIQUE	**BRG**	**CVF**	**GDF**	**MIS**	**ECC**	
Vibration	**3**	**3**	**3**	**3**	**3**	**LOAD SIDE (PUMP)**
Motor Current	**0**	**1**	**0**	**0**	**1**	
Thermography	**2**	**0**	**0**	**0**	**0**	
Flux	**0**	**0**	**0**	**0**	**0**	
Acoustic	**1**	**1**	**1**	**0**	**0**	

Summation of score for each technique capability of detecting faults categorically Electrical and Mechanical tabulation at Table 5.

Table 5: Shows Summation of score for each technique capability

Technique	**Electrical Faults(SWD + RBB)**	**Mechanical Faults(BRG+ CVF+ GDF+MIS+ECC)**
Vibration	3	18
Motor Current	6	3
Thermography	4	4
Flux	5	0
Acoustic	1	5

As pre table 5, it can be stated that for detecting mechanical faults Vibration monitoring is the best CM technique and best alternative is Acoustic.

For Electrical faults Motor Current Analysis is the best CM technique and best alternative is Flux Monitoring.

As per Table 5, Table 6, shows ranking of various technique to find Electrical as well as Mechanical Faults.

Table 6: Ranking of each Technique category wise.

Technique	**Rank for Detecting Electrical faults**	**Technique**	**Rank for Detecting Mechanical faults**
Motor Current	1st	Vibration	1st
Flux Monitoring	2nd	Acoustic	2nd

Thermography	3rd	Thermography	3rd
Vibration	4th	Motor Current	4th
Acoustic	5th	--	--

From fig 02, It has observed that in case of IM mostly the faults occurs are Bearing defect and Stator winding faults are major problem, which causes server damage to the motor. If Stator winding defects then it take lots of time to rewinding and repair the IM, which caused huge production down time in turns losses to the industries (G. Singh et al., 2016).

Table 7, Matrix A' is the motor fault detection priority distribution matrix, the score is proposed according to the criticality of the fault at the primary level.

Table 8, Matrix B' contains the priority for load-side faults, in which pumps are mostly used. Cavitation causes erosion, implosion, misalignment, decrease flow, and greatly reduce efficiency, so it is very important to detect cavitation faults at the incipient level (Dutta et al., 2018; Stopa et al., 2014).

Proposed Score for matrix A' (IM) matrix B' (Pump)

1: Primary level of fault detection is not essential.2: Primary level of fault detection is essential.

Table 7: Shows Motor Fault Priority

Matrix A' Motor Fault Priority			
Technique	SWD	BRG	RBB
Precedence	2	1	1

Table 8: Shows Load Fault Priority

Matrix B' Load Fault Priority					
Technique	BRG	CVF	GDF	ECC	MIA
Precedence	2	2	1	1	1

STEP 1: Determine A_1, A_1 = Mat A * Mat A'

$$A_1 = \begin{bmatrix} A1,1 * A'1,1 & A1,2 * A'1,2 & A1,3 * A'1,3 \\ A2,1 * A'2,1 & A2,2 * A'2,2 & A2,3 * A'2,3 \\ A3,1 * A'3,1 & A3,2 * A'3,2 & A3,3 * A'3,3 \\ A4,1 * A'4,1 & A4,2 * A'4,2 & A4,3 * A'4,3 \\ A5,1 * A'5,1 & A5,2 * A'5,2 & A5,3 * A'5,3 \end{bmatrix}$$

$$A_1 = \begin{bmatrix} 6 & 2 & 1 \\ 2 & 3 & 3 \\ 4 & 2 & 2 \\ 0 & 3 & 2 \\ 2 & 0 & 1 \end{bmatrix}$$

STEP 2, Determine B_1, B_1 = Mat B * Mat B'

$$B_1 = \begin{bmatrix} B1,1 * B'1,1 & B1,2 * B'1,2 & B1,3 * B'1,3 & B1,4 * B'1,4 & B1,5 * B'1,5 \\ B2,1 * B'2,1 & B2,2 * B'2,2 & B2,3 * B'2,3 & B2,4 * B'2,4 & B2,5 * B'2,5 \\ B3,1 * B'3,1 & B3,2 * B'3,2 & B3,3 * B'3,3 & B3,4 * B'3,4 & B3,5 * B'3,5 \\ B4,1 * B'4,1 & B4,2 * B'4,2 & B4,3 * B'4,3 & B4,4 * B'4,4 & B4,5 * B'4,5 \\ B5,1 * B'5,1 & B5,2 * B'5,2 & B5,3 * B'5,3 & B5,4 * B'5,4 & B5,5 * B'5,5 \end{bmatrix}$$

$$B_1 = \begin{bmatrix} 6 & 6 & 3 & 3 & 3 \\ 0 & 2 & 0 & 0 & 1 \\ 4 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 2 & 2 & 1 & 0 & 0 \end{bmatrix}$$

STEP 3: Calculate Motor (IM) Fault detection and fault precedence [IMFDP] by row summation of A_1

$$[IMFDP] = \begin{bmatrix} 6+2+1 \\ 2+3+3 \\ 4+2+2 \\ 0+3+2 \\ 2+0+1 \end{bmatrix} = \begin{bmatrix} 9 \\ 7 \\ 9 \\ 5 \\ 3 \end{bmatrix}$$

STEP 4: Calculate Load (PUMP) fault detection and fault precedence [PFDP] by row summation of B_1

$$PFDP = \begin{bmatrix} 6+6+3+3+3 \\ 0+2+2+2+1 \\ 4+0+0+0+0 \\ 0+0+0+0+0 \\ 2+2+1+0+0 \end{bmatrix} = \begin{bmatrix} 21 \\ 7 \\ 4 \\ 0 \\ 5 \end{bmatrix}$$

Proposed Score for matrix C, D, E

The Score of the matrix are proposed depending on the real time importance of the factor consider bythe industries for implementation of the particular CM technique.

Matrix C: Cost factor (CF)

1: Technique implementation cost is higher.

2: Technique implementation cost is moderate.3: Technique implementation cost is lower.

Matrix D: Easy Data collection System (EDS)

1: Data collection required skill manpower.2: Data collection is semi-automatic.

3: Unmanned Data collection way.

Matrix E: Noise Factor (NF)

1: Technique is sensitive to Background noise.

2: Technique is not sensitive to Background noise.

Table 9 Shows proposed score for matrix C,D,E for total system shown in fig 07, (IM and PumpCouple set)

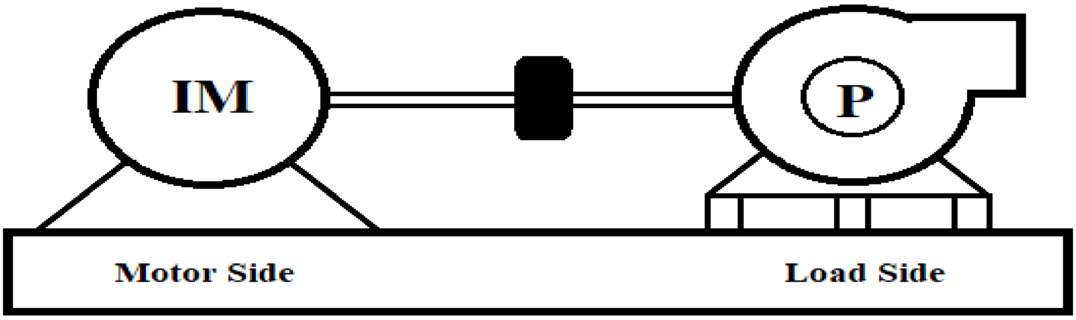

Fig 07, Shows IM-Pump couple set

Table 9: Show various CM technique and their CF,EDS, NF weightage.

Technique	CF	EDS	NF
Vibration	2	2	2
Motor Current	3	2	2
Thermography	3	1	2
Flux	3	1	2
Acoustic	3	1	2

STEP 3: MCDM matrix is prepared using the parameters technique, criteria and weights allocatedshown in table xx and normalized value shown in table xx.

Weightage is assigned to each factor:

WIM: Fault detection and priority on the IM side. WP: Fault detection and priority on the Pump side. WCF: Cost to implement the technique on the asset.

WED: Easy data collection system (Using sensor and data transmission system).WNF: Noise factor associated with a technique.

Table 10: MCDM matrix

Weightage	**WIM**	**WP**	**WCF**	**WED**	**WNF**
Technique/Criteria	IMFDP	PFDP	CF	EDS	NF
Vibration	9	21	2	2	2
Motor Current	7	7	3	2	2
Thermography	9	4	3	1	2
Flux	5	0	3	1	2
Acoustic	3	5	3	1	2

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Weightage	WIM	WP	WCF	WED	WNF
hnique/Criteria	IMFDP	PFDP	CF	EDS	NF
Vibration	1	1	0.667	1	1
Motor Current	0.778	0.334	1	1	1
Thermography	1	0.19	1	0.5	1
Flux	0.556	0	1	0.5	1
Acoustic	0.334	0.238	1	0.5	1

STEP 4 : Calculate **TCS** Of Individual Technique For Both Electrical And Mechanical Faults.

Table 11: Formula of TCS for Individual Technique.

Technique	FORMULA OF TCS BY MCDM
Vibration	WIM*1+WP*1+WCF*.667+WED*1+WNF*1
Motor Current	WIM*.778+WP*.334+WCF*1+WED*1+WNF*1
Thermography	WIM*1+WP*.19+WCF*1+WED*.5+WNF*1
Flux	WIM*.556+WP*0+WCF*1+WED*.5+WNF*1
Acoustic	WIM*.334+WP*.238+WCF*1+WED*.5+WNF*1

STEP 5: Calculate TCJS

To find TCJS we have to observe Table 06 conclusion carefully.

Justification

1: Combination of the technique cannot detect both Electrical and Mechanical faults, either detect Electrical or Mechanical Fault.

2: Combination of the technique can detect Electrical and Mechanical faults at primary level.

Table 12: TCJS of combination of technique.

Technique	TCJS
Vibration + Motor Current	2
Vibration + Flux	2
Vibration + Thermography	1
Vibration +Acoustic	1
Motor Current + Acoustic	2
Motor Current +Flux	1
Motor Current+ Thermal	1
Acoustic + Flux	1
Thermal + Flux	1

Justification

1: Combination of the technique cannot detect both Electrical and Mechanical faults, either detect Electrical or Mechanical Fault.

2: Combination of the technique can detect Electrical and Mechanical faults at primary level.

STEP 5: Calculate Normalization TCJS (NTCJS)

Table 13: NTCJS of combination of technique.

Technique	NTCJS
Vibration + Motor Current	1
Vibration + Flux	1
Vibration + Thermography	0.5

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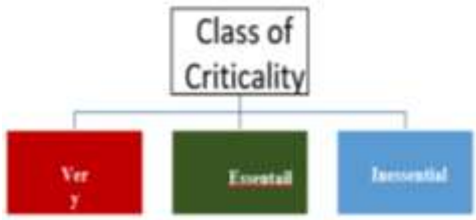
Vibration +Acoustic	0.5
Motor Current + Acoustic	0.5
Motor Current +Flux	0.5
Motor Current+ Thermal	0.5
Acoustic + Flux	0.5
Thermal + Flux	0.5

Step 6: Calculate Technique Combination Credit Score (TCCS)

TCCS tells us the best combination of CM technique feasible for real time application, depending on various dimensional parameters such as priority of critical fault detection system, Cost to implement, how easy data collection system is (using various sensor and transduces, recorder and data transmission system), generally chances of error is less for easy data collection system. If position of sensor or transduces are placed in odd place, from where data collection from human is difficult, chances of getting wrong or biased data getting more. Noise sensibility associated with a technique for total system(IM and Pump).

All the parameters are anticipate carefully & properly before giving final ranking to the combination ofCM techniques.

Requirement for implementation of Condition Monitoring system across the industrial sectors (Oil & Gas, Power Plants, Agro, Dairy, Chemical etc.) across various system is different and can be classifiedinto three different class (V-E-I)



The class of criticality design based on importance of cost, importance of downtime, effectiveness, ease of implementation, simplicity, outside factors, importance of shutdown cost, and maintenance policy. (Bellini et al., 2008; Guoji et al., 2014; Henriquez et al., 2014; Schütze et al., 2018; Shin & Lee, 2015;Trajin et al., 2010; Uddin et al., 2014; Zhang et al., 2012).

Very Critical system can be referred to such system where a breakdown or shutdown cannot be to tolerable. Hence main focus is to minimize breakdown of the system (IM + Pump), hence 70% weightage is given to fault detection system and fault precedence parameter. Whereas other parameterssuch as cost, data collection system and background noise are given 10% each.

Essential Critical system are those system, where downtime call be allowed for few hours until maintenance team repair the system, hence 50% weightage is given to fault detection system and fault precedence parameter, and 40 % to cost of implementation.

Inessential Critical system can be referred to such system where either downtime is not a major factor for profit maximizing or they have alternate system. Hence here implementation of CM is not necessary then cost of implementation of CM technique. 70% weightage is assigned to the cost of implementation. 20% to weightage is given to fault detection system and fault precedence.

Table 14, shows weightage of each parameters for V-E-I criticality by expert opinion.

Criticality	Very	Essential	Inessential
Weightage			
WIM	35% (.35)	25% (.25)	10% (.10)
WP	35% (.35)	25% (.25)	10% (.10)
WCF	10% (.10)	40% (.25)	70% (.70)
WED	10% (.10)	5% (.50)	5% (.50)
WNF	10% (.10)	5% (.50)	5% (.50)

Step 7: Find TCCS for Very Critical system and rank of the combination of various CM technique

Referring to Table no 14 putting the value of WIM, WP, WCF, WED, WNF for Very Critical system at table no 15.

Table No 15: Value of TCS of individual CM technique.

Technique	TCS BY MCDM	TCS
Vibration	0.35*1+0.35*1+0.1*.667+0.1*1+0.1*1	0.9667
Motor Current	0.35*.778+0.35*.334+0.1*1+0.1*1+0.1*1	0.6892
Thermography	0.35*1+0.35*.19+0.1*1+0.1*.5+0.1*1	0.6665
Flux	0.35*.556+0.35*0+0.1*1+0.1*.5+0.1*1	0.4446
Acoustic	.035*.334+.035*.238+0.1*1+0.1*.5+0.1*1	0.2700

Now calculate, Technique Combination Credit Score (TCCS) = [TCS1 + TCS2]* NTCJS

Table 16: Technique Combination Credit Score (TCCS) for Very critical system.

Technique Combination	TCJS	
Vibration + Motor Current	(TCS VIBRATION +TCSMOTOR CURRENT)* 1	1.6557
Vibration + Flux	(TCS VIBRATION +TCSMOTOR FLUX)*1	1.4113
Vibration + Thermography	(TCS VIBRATION +TCSTHERMOGRAPHY)*0.5	0.8166
Vibration +Acoustic	(TCS VIBRATION +TCSACOUSTIC)*0.5	0.6185
Motor Current + Acoustic	(TCS ACOUSTIC +TCSMOTOR CURRENT)*0.5	0.4796
Motor Current +Flux	(TCS FLUX +TCSMOTOR CURRENT)*0.5	0.5669
Motor Current+ Thermal	(TCS THERMAL +TCSMOTOR CURRENT)*0.5	0.6778
Acoustic + Flux	(TCS ACOUSTIC+TCSFLUX)*0.5	0.3573
Thermal + Flux	(TCS THERMAL+TCSFLUX)*0.5	0.5555

Table 16: Shows ranking table for Technique Combination Credit Score (TCCS) for Very Critical System.

Technique Combination	TCJS	RANK
Vibration + Motor Current	1.6557	1ST
Vibration + Flux	1.4113	2ND
Vibration + Thermography	0.8166	3RD
Motor Current+ Thermal	0.66778	4TH
Vibration +Acoustic	0.6185	5TH
Motor Current +Flux	0.5669	6TH
Thermal + Flux	0.5555	7TH
Motor Current + Acoustic	0.4796	8TH
Acoustic + Flux	0.3573	9TH

As per Table no 16, it can easily state that for **Very critical system** combination of **Vibration Monitoring and Motor Current Monitoring is the best combination** for making full prove system to prevent breakdown and reduce intolerable downtime.

Condition Monitoring Technique comparison charts is prepared to perceive when vibration monitoring technique is used independently and when it is used with other techniques are shown in Figure 8

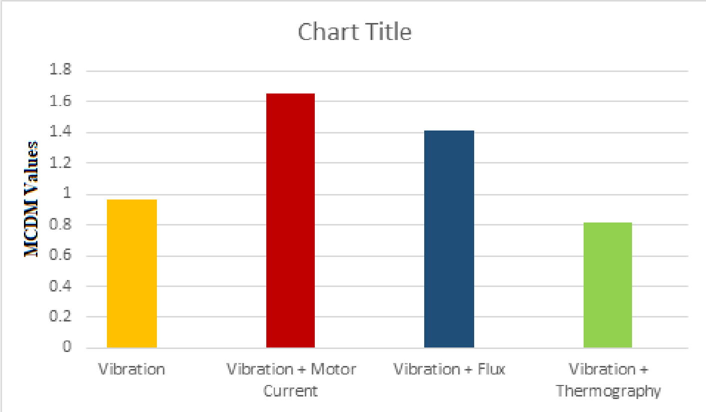


Fig 08, Technique comparison charts, Vibration Vs Vibration Combination CM technique

This chat is an evidence that if only vibration Monitoring is applied for Motor (IM) and Load (Pump)to detect fault, it will fail to detect electrical faults primary, henceforth if electrical faults occur, the system will be interrupted. Vibration and Thermography is not good combination because from matrix A it can be stated that Thermography Technique is unable to detect electrical faults at primarylevel.

Condition Monitoring Technique comparison charts is prepared to perceive when Motor Current monitoring technique is used independently and when it is used with other techniques are shown in Figure 9

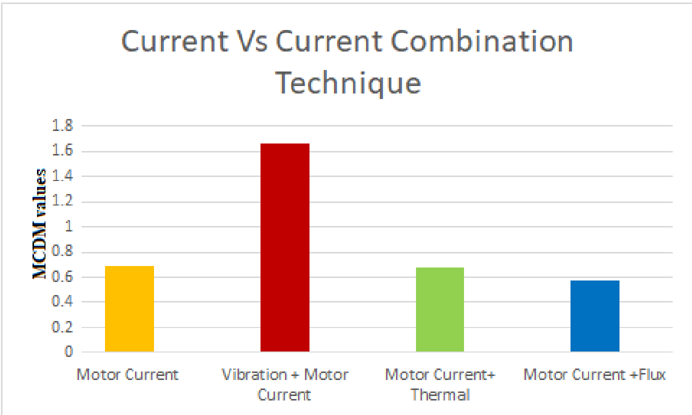


Fig 09, Technique comparison charts Motor Current Vs Motor Current Combination CM technique

This chat is an indication that if only Motor Current Monitoring is applied for Motor (IM) and Load(Pump) to detect fault, it will fail to detect Mechanical faults primary, henceforth if any mechanical faults occur, the system will be collapse. Combination of Motor Current Monitoring, Thermography Monitoring, and Flux Monitoring is use to detect electrical faults only, hence combination of such faults is waste of money.

For Essential Critical system

Referring to Table no xx putting the value of WIM, WP, WCF, WED, WNF for Essential Critical systemat table no 17

Table No 17: Value of TCS of individual CM technique.

Technique	TCS BY MCDM	TCS
Vibration	0.25*1+0.25*1+0.4*.667+0.05*1+0.05*1	0.866
Motor Current	0.25*.778+0.25*.334+0.4*1+0.05*1+0.05*1	0.778
Thermography	0.25*1+0.25*.19+0.4*1+0.05*.5+0.05*1	0.772
Flux	0.25*.556+0.25*0+0.4*1+0.05*.5+0.05*1	0.614
Acoustic	0.25*.334+.025*.238+0.4*1+0.05*.5+0.05*1	0.564

Now calculate, Technique Combination Credit Score (TCCS)

Table 18: Shows ranking table for Technique Combination Credit Score (TCCS) for Essential System.

Technique Combination	TCCS= [TCS1 +TCS2]* NTCJS	RANK
Vibration + MotorCurrent	1.644	1^{ST}
Vibration + Flux	1.481	2^{ND}
Vibration + Thermography	0.819	3^{RD}
Vibration +Acoustic	0.715	4^{TH}
Motor Current +Flux	0.696	5^{TH}
Thermal + Flux	0.693	6^{TH}
Acoustic + Flux	0.589	7^{TH}
Motor Current +Acoustic	0.4172	8^{TH}

As per table no xx, Vibration Monitoring and Motor Current Monitoring is best combination technique, Vibration Monitoring and Flux Monitoring is best alternative for Essential Critical Systemto detect both IM-Pump fault. In-case of Essentially Critical System production downtime as well as Cost of technique implementation both the parameter is important. Hence to make a perfect trade-off between this almost opposite polarity factor was a challenging task.

In case of Inessential system, where breakdown does not effect in profit maximization of an industry, it is not necessary to implement CM technique, because cost of implementation of CM will not provide any return of investment (ROI). Hence routine maintenance strategy will be best for such system.

4. CONCLUSION

CRITICALITY	TECHNIQUE COMBINATION	RANK
Very	**Vibration Monitoring + MotorCurrent Monitoring**	1^{st}
	Vibration Monitoring + Flux Monitoring	2^{nd}
Essential	**Vibration Monitoring + MotorCurrent Monitoring**	1^{st}
	Vibration Monitoring + Flux Monitoring	2^{nd}
Inessential	-------	------

Table 19: Shows a evaluation of various combination of CM technique in V-E-I condition and theirrank.

As per Table 19, this paper is an evidence that **Vibration Monitoring & Motor Current Monitoring** is best combination of CM technique for fault detection of IM-Pump (Motor-Load) set, the combinationis perfect for detecting mechanical as well as electrical faults at primary level. At the same time the combination is also cost effective, easy to collect data and less sensible to back ground noise which create unwanted signal to the data. This research tries to solve the practical problem on the basis of various parameters for a feasible sophisticated solution. Hence it gives flexibility to choose best combination on the basis of criticality level also. WSM-MCDM is use as mathematical tool which is very simple but efficient in giving best choice between multiple criteria and conditions.

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