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Title: Compensación de potencia reactiva considerando un modelo de gestión de mantenimiento en una planta industrial

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Content

Introduction

The changes that are occurring in the electrical grids demand management strategies that allow an optimization of critical assets at the generation, distribution, transmission and sub-transmission level, resulting in better profitability, risk control, operational reliability, energy saving and efficiency [1,2,3].

Electric energy efficiency has been an area where strategies have been implemented where many times it fails to consolidate, because it has been focused mainly on effectiveness (short-term actions) and not on efficiency (medium and long-term actions) and evaluation, having an emphasis many times on billing costs without considering the impacts that can occur in the maintenance, reliability and profitability of a plant[4,5].

Introduction

On the other hand, it is very common to observe the need to have an asset management model that considers aspects of energy saving and efficiency, maintenance, reliability and profitability in industrial plants in an aligned way, otherwise undesirable situations may arise. In Fig. 1. it can be seen that there must be a hierarchical level.

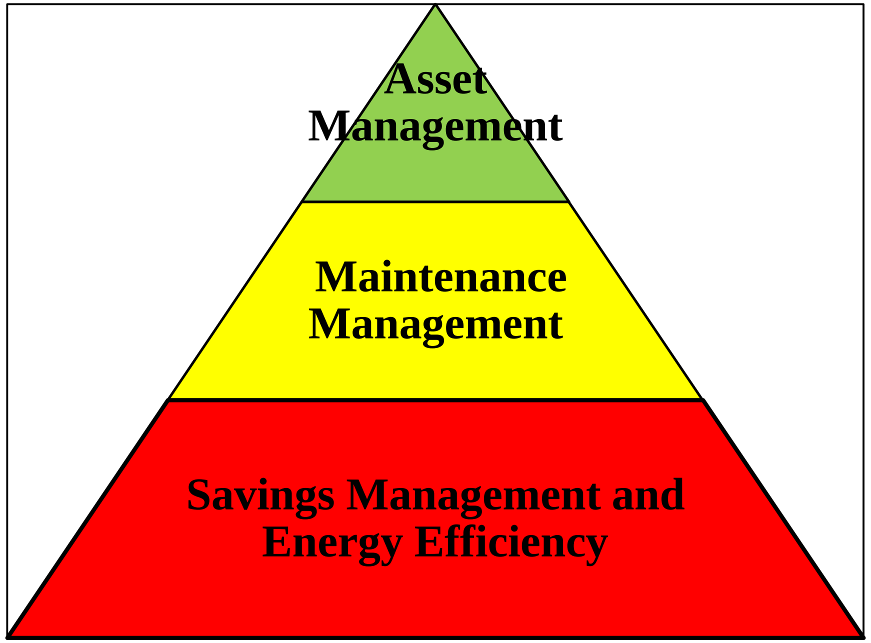

Fig. 1. Considerations in energy efficiency management

A consolidated maintenance management model in electrical systems involves the use of tools and methodologies that allow adding value.

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Methodology

Maintenance management model used in electrical systems

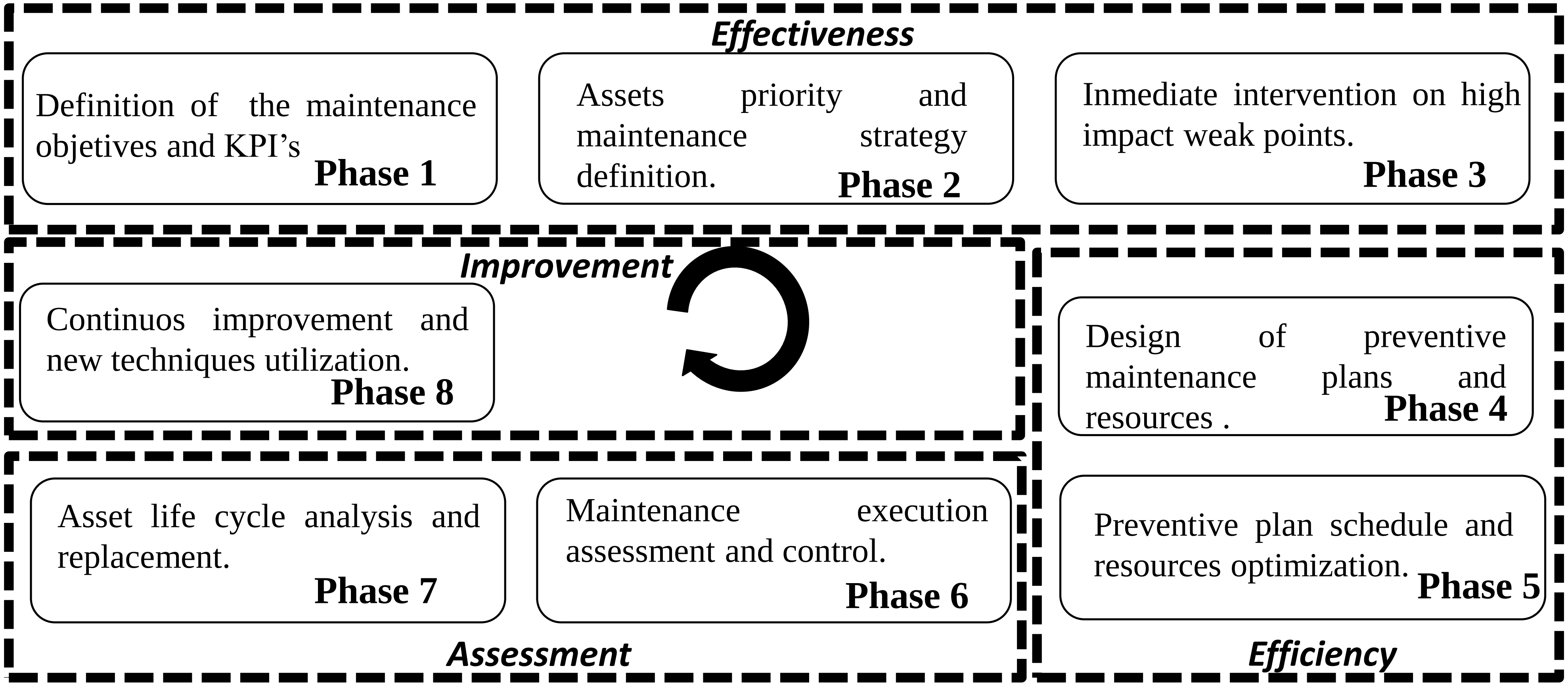

Fig. 2. Maintenance Management Model aligned to asset management in electrical systems [5,6].

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Methodology

Asset management in electrical systems

Asset management can be defined as the set of activities and practices, systematic and coordinated, that an organization uses to ensure that its assets deliver results and objectives in a consistent, optimal and sustainable manner, managing risk [8]. This definition of asset management represents significantly greater scope considering that energy efficiency and maintenance must be aligned with it.

Fig. 3. Current situation in the national electricity system

Methodology

Asset management in electrical systems

Nowadays, some standards have begun to emerge, such as the ISO 55000/01/02 series of guides, which mention recommendations for managing assets throughout the life cycle [10,11,12], where it is recommended to be able to integrate the use of technical indicators with financial indicators.

Fig. 4. ISO 55000/01/02 series of guides.

Methodology

Conventional technical methodology for reactive power compensation solutions.

$$I_L = \frac{P}{\sqrt{3} \times V_{LL} \times PF}$$

$$I_{CC} = \frac{S_{CC}}{\sqrt{3} \times V_{LL}}$$

$$PF = \frac{P}{S}$$

$$PF = \frac{kWh}{\sqrt{kWh^2 + kVArh^2}}$$

$$Q = P(\tan\theta_1 - \tan\theta_2)$$

$$APLPF = Bill\left(\frac{3}{5}\right)\left(\frac{0.9}{FP} - 1\right)(12)$$

$$ABPF = -Bill\left(\frac{1}{4}\right)\left(1 - \frac{0.9}{FP}\right)(12)$$

$$ROI = \frac{\$_{solution}}{\$_{Annual\ saving}}$$

Fig. 5. Conventional solution of low power factor

Methodology

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Reliability, maintenance and economic management indicators

$$MTTF = \frac{\sum_{i=1}^{i=n} TTF_i}{n}$$

$$Ao = \left(\frac{MTTF}{MTTF+MDTTR}\right)100\%$$

$$AMC = PMC + MMC + CUR$$

$$ff = \frac{1}{MTTF}$$

$$CUR = (ff)(TOS)(PC)$$

$$NI = (PI)\,(Ao)$$

$$MDTTR = \frac{\sum_{i=1}^{n} DTTR_i}{n}$$

$$ATR = AC + OC + MMC + PMC + CUR$$

$$EBITDA = NI - AMC - OC - AE - SE + DA$$

$$TOS = TOC + MDTTR$$

Cost of unavailability in reliability
Annualized Total Risk
Earning Before Interest Taxes Depreciation Amortization

Results

Case study. Optimized reactive power compensation.

Table I. Technical maintenance and reliability data for the transformer.

Technical-operational problems		Costs to mitigate
Low *PF* of 0.70	Impacts on	Costs of penalties in energy billing and non-compliance with regulations
Transformer with overload (103%)	Impacts on	Corrective maintenance costs and penalties
Feeders with improper currents	Impacts on	Corrective maintenance costs and penalties

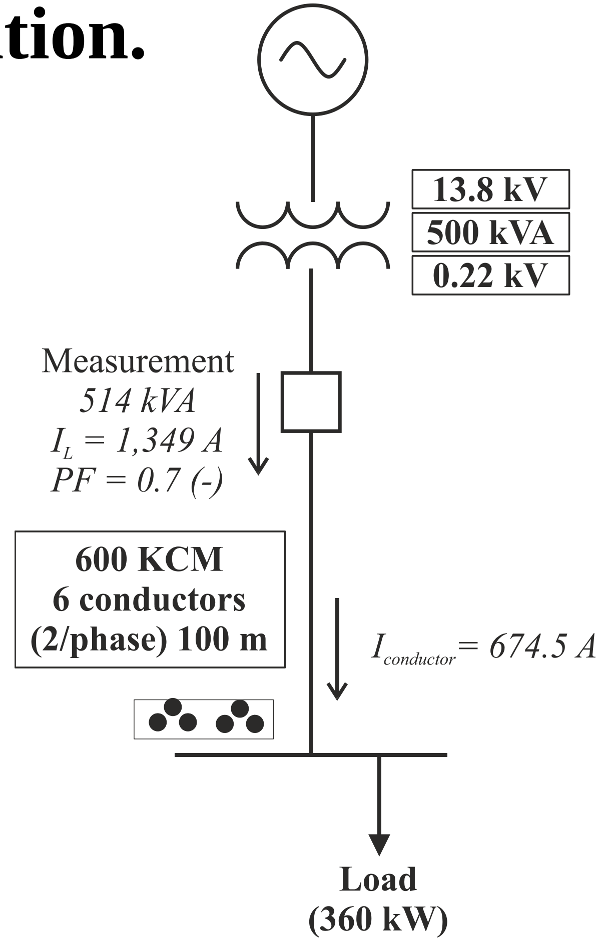

Fig. 6. Current system

Results

Case study. Optimized reactive power compensation.

Table II. Initial system billing

Concept	Amount	Charge
kWh	210,000	
kVArh	214,254	
PF	0.7	$118,349.8
kW max	360	
$/kWh	$2.85	$598,588.2
$/kW 2% LV	$85.00	$30,600
$/kW Charge	$170.00	$61,200
TOTAL		**$808,738.75**

Table III. System billing with compensation

Concept	Amount	Charge
kWh	204,389	
kVArh	69,034	
PF	0.95	-$8,437.28
kW max	360	
$/kWh	$2.85	$582,454.5
$/kW 2% LV	$85.00	$30,600
$/kW Charge	$170.00	$61,200
TOTAL		**$665,871.07**

$$P = 674.5^2(0.00753) = 3.425\ kW$$

$$P = 497.23^2(0.00753) = 1.861\ kW$$

$$Q = 360(\tan(45°) - \tan(15°)) = 250\ kVAr$$

$$ROI = \frac{\$250{,}000.00}{(\$808{,}738.75 - \$665{,}871.07)} = 1.74\ \text{months}$$

Results

Case study. Optimized reactive power compensation.

Table IV. Balanced scorecard, showing technical and financial indicators.

Strategic objetives	Measures (KPI's)	Goals	Action	Perspective
Improve profitability considering the maintenance, reliability and efficiency and saving of electrical energy in the plant	Power Factor (*PF*), Electric Power Billing Costs in impacts on reliability and maintenance (*CUR*), Annualized Total Risk Indicator (*ATR*) *EBITDA* financial indicator	Increase profitability Improve maintenance, Improve reliability Improve energy savings and efficiency Decrease in operating costs (electrical energy)	Ensure adequate data acquisition (Billing costs, Evaluation of Cost-Risk-Benefit solutions) Simulations with software to avoid unwanted events (resonances) Development of new internal policies (acquisition, reengineering)	Financial Customers Internal processes Learning and growth

Results

Case study. Optimized reactive power compensation.

Table V. Technical maintenance and reliability data for the transformer

Key Performance Indicators	Transformer
$MTTF_{Tranf}$ *(years)*	20
ff_{Tranf} *(Failure/year)*	0.05
$MDTTR_{Tranf}$ *(hour/failure)*	72
TOS_{Tranf} *(hour/failure)*	72
PC_{Tranf} *($/hour)*	5,000.00
MC_{Tranf} *($/year)*	24,000.00
AC_{Tranf} *($)*	750,000.00

Table VI. Technical maintenance and reliability data for the capacitor banks

Key Performance Indicators	Capacitor Bank Type 1	Capacitor Bank Type 2
$MTTF_{Cap}$ *(years)*	4	1
ff_{Cap} *(Failure/year)*	0.25	1
$MDTTR_{Cap}$ *(hour/failure)*	24	24
TOS_{Cap} *(hour/failure)*	24	24
PC_{Cap} *($/hour)*	164.37	164.37
MC_{Cap} *($/year)*	3,000.00	3,000.00
AC_{Cap} *($)*	250,000	150,000

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Results

Table VII. Scenario evaluation using technical and financial indicators.

Key Performance Indicators	Actual condition	Condition with type 1 capacitor bank	Condition with type 2 capacitor bank
PF	0.7	0.95	0.95
Total CUR ($/year)	36,000.00	37,972.50	43,889.99
ATR ($/year)	9,802,364.95	8,155,425.31	8,248,842.80
TMC ($/year)	60,000.00	64,972.50	70,889.99
OC ($/year)	9,704,864.95	7,990,452.82	7,990,452.82
Ao	0.9992	0.9991	0.999
PI ($/year)	10,000,000.00	10,000,000.00	10,000,000.00
NI ($/year)	9,991,787.57	9,990,875.91	9,989,573.83
AE($/year)	20,000.00	20,000.00	20,000.00
SE($/year)	30,000.00	30,000.00	30,000.00
DA($/year)	300,000.00	300,000.00	300,000.00
EBITDA($/año)	476,922.62	22,185,450.60	2,178,231.03

Cost of unavailability in reliability

Annualized Total Risk

Earning Before Interest Taxes Depreciation Amortization

Annexes

1.- Generate a list of problems / events giving a hierarchy of importance and form the high performance team.

Technical-operational problems		Costs to mitigate
Low *PF* of 0.70	Impacts on	Costs of penalties in energy billing and non-compliance with regulations
Transformer with overload (103%)	Impacts on	Corrective maintenance costs and penalties
Feeders with improper currents	Impacts on	Corrective maintenance costs and penalties

Billing costs of penalties in energy consumption, regulations, production and corrective maintenance.

2.- Define the problem, describe it using a fault event tree diagram and physical evidence.

Concept	Amount	Charge
kWh	210,000	
kVArh	214,254	
PF	0.7	$118,349.8
kW max	360	
$/kWh	$2.85	$598,588.2
$/kW 2% LV	$85.00	$30,600
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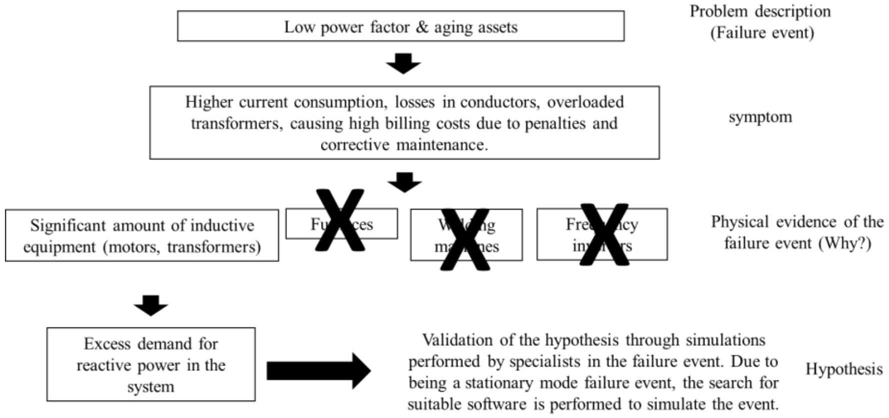

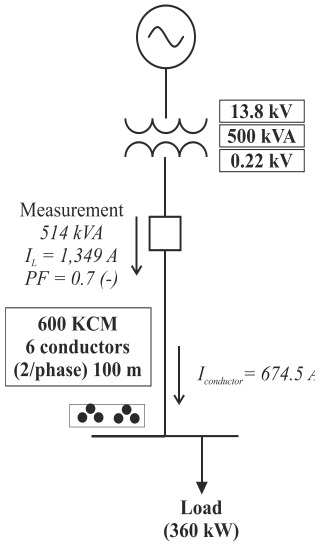

Current system

3.- Formulate the hypotheses and check them.

Concept	Amount	Charge
kWh	204,389	
kVArh	69,034	
PF	0.95	-$8,437.28
kW max	360	
$/kWh	$2.85	$582,454.5
$/kW 2% LV	$85.00	$30,600
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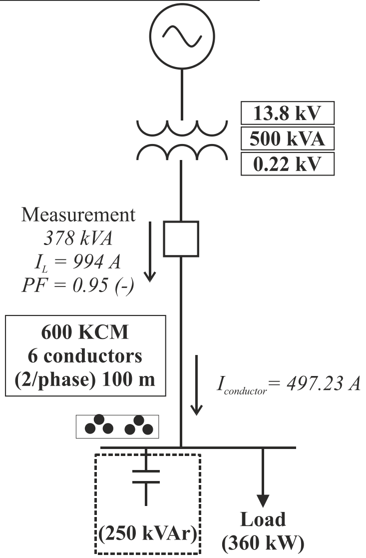
TOTAL		**$665,871.07**

$$ROI = \frac{\$250{,}000.00}{(\$808{,}738.75 - \$665{,}871.07)} = 1.74 \text{ months}$$



Proposed system

4.- Specify human and latent causes.

Ignorance of the power quality failure event
There are not procedures that consider the power factor, harmonic distortion and other events in the electrical design
There is not a maintenance management model in the organization that considers continuous improvement tools such as RCA, key perfomance indicators that using a

5 .- Solutions and recommendations.

Installation of capacitors bank with higth reliability
Implementation and development of a maintenance management model aligned to the management objectives.
Implement procedures and policies in relation to modifications of the electrical design that avoid the recurrence of the failure event.

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Conclusions.

The problem of improving the power factor in an industrial plant is very common, mainly in installations with several industrial loads, where selecting a technical solution for reactive power compensation problems requires considering additional factors such as maintenance, reliability and financial indicators. In this work, indicators allow to justify criteria that improve the profitability of a plant considering aspects of reliability, maintenance, energy saving and financial. Through a maintenance management model that considers energy savings and efficiency aligned with asset management, it is possible to analyze recurring problems through the proposed phases 1, 2, 3 and 6, that considering the most appropriate condition for the plant.

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