EUROPEAN PROGRAMME
DEXA MCP

«DISSEMINATION, EXTENSION AND APPLICATION OF THE MOTOR CHALLENGE PROGRAMME»

ELECTRICAL DISTRIBUTION MODULE

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1. Introduction to the Electrical Distribution Module document

This document is subsidiary to the Motor Challenge Programme (MCP) "Partner Guidelines". It defines what an MCP Partner Action Plan should cover, if the Partner company's commitment includes electrical network distribution[1]. In particular, it explains what a Partner does for each of the following steps of participation in the Motor Challenge:

- **Inventory** of electrical distribution components and system functioning
- **Assessment** of the applicability of possible energy savings measures
- **Action Plan**, presented to the Commission, which defines what the Partner has decided to do to reduce operating costs by improving energy efficiency
- **Annual report** of progress on the Action Plan.

Note that documents relating to the Inventory and the Assessment are in house, confidential documents, while the Action Plan and Annual Report are reported to the Commission.

2. Overview

An industrial electrical distribution network has to fulfill different needs:

- an optimal industrial process operation,
- people safety and security,
- equipment protection,
- a continuous and qualitative power supply.

This module covers the different elements of an industrial electrical distribution system:

- industrial transformers
    - dry type (primary voltage up to 24 kV, rated power range from 50 to 2 500 kVA)
    - liquid filled (primary voltage up to 12 kV, rated power range from 100 to 2 500 kVA)
- protection equipments
    - measure elements (voltage, current)
    - monitoring (relay)
    - interruption (interrupters, fuse)
- cables
- switchgear
    - high power switches
    - separators
- other...

3. Inventory

In this section is described the first step to identify the possible energy saving actions. An MCP Partner has to build an inventory of the distribution network elements with their main operating characteristics. This inventory is divided in four phases.

Distribution system features

An electrical distribution network is characterized by different elements, such as the architecture, the size, the operating modes, the earthing system, the type of sources and

[1] Refer to the "Partner Guidelines" for an explanation of terms such as "Partner", "Action Plan" and "commitment".

loads, the types and characteristics of distribution transformers, the eventual specific needs and the power supply properties required.

Network description

The more or less continuous power supply depends directly on the electrical network design. As cost and complexity of an electrical network are related to each other, the architecture choice is therefore a compromise between technical and economical criteria. Select in the following list and sub-lists the architecture type of your distribution network.

radial	loops	with energy generating set (“genset”) included
- simple radial feeder or “single power supply” - dual power supply - double radial feeder - double radial feeder with dual bus bar	open loop closed loop	local genset, replacement source

Distribution transformer

For each distribution transformer, fulfill the following characteristics.

1. Rated power (VA) 2. Primary and secondary rated voltages (kV) 3. Off-load / on-load tap changer 4. Type (liquid filled / dry) – if liquid type, precise the type of liquid used (oil, other) 5. Coupling 6. No-load losses, P_0 (kW) 7. Load losses, P_k (kW) 8. Cooling type (ONAN, ONAF, natural or forced ventilation...) 9. Age 10. Reparations performed (rewinding...)	11. Protection auxiliary equipments a. against internal outages (top oil thermometer, RGPT, Bucholz relay...) b. against overloads (disconnecter protection relay, fuse...) 12. Auxiliary equipments a. counter b. capacitors for reactive energy compensation 13. Thermal class 14. Type of maintenance (visual checking, oil change, measurements…)

Earthing systems

Describe the earthing system of your electrical distribution network: TT, TN-C, TN-S, IT.

Documentation and assessment of operating parameters

The assessment of operating parameters requires measure equipments and a relative good knowledge of electrical networks. Ideally, permanent measure equipments should be installed within the network, in order to allow a continuous monitoring system operation.

Elementary measures

(1) Apparent (S), active (P) and reactive (Q) powers (VA, W, VAR) (2) RMS voltage and current values (3) Power factor (PF=P/S) or current-voltage phase shift cosine (4) Load factor (%) or load profile (5) Operation duration (hours/year)	(6) Sound level (dB) (7) Voltage dips, swells and Interruptions (8) Total harmonic distortion (THD) (9) Voltage imbalance (10) Operating temperature

Without any measure equipment available, one possible line of action is to perform a qualitative analysis of the system: the system disturbances and temperature deviations not retraceable to load deviations should be considered as symptoms of possible electrical disturbances.

Detailed inventory

A detailed inventory (optional) requires advanced measures, and probably an external help, to assess the following parameters.

(1) Polarity and vector diagram (2) Windings resistance (including temperature correction) (3) No-load losses (including temperature correction), P_0 in kW	(4) Load losses P_k in kW, direct and zero-sequence impedances (including temperature correction), (5) Harmonics and Inter-harmonics spectrum (6) Operating temperature

Global performance indicators

On the basis of data collected, the following performance indicators of your electrical distribution network can be assessed.

1. Apparent, active, and reactive powers 2. Power factor (PF=P/S) or current-voltage phase shift cosine 3. Current 4. Voltage imbalance	5. Short interruptions, long interruptions (max/min/average duration) 6. Severity and number of voltage dips and swells 7. Total harmonic distortion (THD)

Note that your distribution network power quality depends on your distributor *and* on your architecture network design and characteristics of machines and equipments.

Abnormal operation symptoms

Electrical networks and machinery are mainly suffering from four defaults:

- short circuit (phase/phase or phase/neutral),
- overloads,
- rotating equipments defaults
- and poor power quality caused by electronic equipment, oven, etc.

As an example, overheating and inverse motor torque are usually symptoms of phase imbalance greater than 2%.

Although motors typically tolerate small voltage variations relative to the nominal voltage, operating a motor at other than nameplate voltage may reduce its efficiency. This, in turn, shortens sometimes the motor life by overheating the insulation and lubrication systems. For example a motor operated at 10% below the rated voltage produces about 80% of its design torque. The motor operating at high load levels will draw more current and may become overloaded, leading to overheating and to its premature failure.

4. Energy savings actions technical assessment

The energy savings actions presented in this module are divided in the following applications:

- operation,
- maintenance,
- upgrades
- and design / new installation.

Operation

The **reactive power** consumed by the magnetic circuit of loads such as motors or fluorescent lightning leads to an increase of the circulating current in cables and ducts for the same active power. The current-voltage shift has various impacts deteriorating the power quality:

- extra Joule losses on the global distribution network (α RI^2),
- overloading and overheating of transformers with a limited available active power,
- end-line voltage drop with abnormal operation of sensitive loads,
- reduce expected life time of motors and transformers,
- financial penalty paid to the energy supplier.

A reactive power compensation allows to reach a cos φ feasible to allow not just the savings in the electrical bill but also to mitigate the impacts of reactive power currents. The value of the cos φ feasible, depends on the penalties given by each country utility, but usually is between 0,93 and 0,97. The compensation needs to be adapted and regulated to the real time reactive power to compensate.
The investment necessary to improve the installation power factor has a typical payback time around 6 months to 1.5 years, depending on the company operating hours.

Reduction of harmonic distortion
Harmonic currents circulating in a distribution network cause not only deteriorations of the power quality (wave form, frequency), but also generate losses up to 10% in cables, transformers and loads. The Eddy current losses, about 10 % of total losses at full load, increase with the square of the harmonics current. Generally, transformers are de-rated when non-linear loads are supplied. We recommend the use of class K transformers, specially designed to minimize Eddy current losses when harmonic currents occur.

The table below summaries the different possible actions to enhance and improve the energy efficiency of the operation application.

Description	Savings	Frequency	Feasibility	Skill required
Enhance the power factor thanks to local (capacitor, variation speed drive and harmonics filtering) or central compensation		One time	+	in-site
Reduce the Joule losses by over sizing cable			-	-
Consider harmonics filtering (anti-harmonic choke, passive or active filter, hybrid filter, line choke, increased the short circuit power, Scc), contain polluting loads or derate equipment	Joule losses reduction by 10% Eddy current losses (10% of total losses)		+	external
Consider the installation of series reactance to solve the inter-harmonics disturbances	reduction by 30% of the flicker			external
Install local energy measure equipment (by unit / floor / service). The behavior change depending on the way the energy charges are handled.				external
Install electromechanical reactive power compensator, real time reactive compensator, series electronic conditioner, tap changer to solve **voltage fluctuations**	flicker reduction from 25 up to 50%			external
Infra-red thermography to identify possible overheating of transformers windings caused by harmonics			++	in-site or external
Consider UPS, real time reactive	Depends on the	One time		external

compensator, dynamic electronic voltage regulator, soft starter, series electronic conditioner, increase the short circuit power to **solve voltage dips** disturbances Modify the discrimination of protective devices	sensibility of the company equipments and number of voltage dips [see examples in tables 1 and 2]			
Consider UPS, distributed generations, mechanical source transfer, static transfer switch, zero time set, shunt circuit breaker, remote management to solve **power interruptions**	See some examples in the table 2	One time		external
Consider shunt electronic compensator, dynamic electronic voltage regulator, increase the short circuit power to balance the loads and prevent inverse motor torque or overheating of asynchronous machines				external

The two tables below indicate some examples of economic losses, due to a voltage dip or a momentary interruption of electricity in different factories (source: Electrotek Concepts).

Table 1 – Examples of economical loss by voltage dip, in three different companies.

	Economical loss by voltage dip
Semiconductor manufacturing	**3 800 000 €**
Iron industry	**350 000 €**
Glass companies	**250 000 €**

Table 3 – Cost of momentary interruption (1 minute), in €/kW demand.

	Cost of momentary interruption (€/kW demand)	
	Minimum	Maximum
Automobile manufacturing	**5.0**	**7.5**
Rubber and plastics	**3.0**	**4.5**
Textile	**2.0**	**4.0**
Paper	**1.5**	**2.5**
Printing (newspapers)	**1.0**	**2.0**
Petrochemical	**3.0**	**5.0**
Metal fabrication	**2.0**	**4.0**
Glass	**4.0**	**6.0**
Mining	**2.0**	**4.0**
Food processing	**3.0**	**5.0**
Pharmaceutical	**5.0**	**50.0**
Electronics	**8.0**	**12.0**
Semiconductor manufacturing	**20.0**	**60.0**

Maintenance

A regular preventive maintenance allows to avoid operating faults. For example, the failure of a transformer may lead to important or dramatic consequences, by shutting down an installation power supply, with a possible global manufacturing shutdown.

Description	Savings	Frequency	Feasibility	Skill required
Clean bushings and connections (to prevent from corrosion risks) – the contact surface has to be large and clean **Tighten** bus bar **Check protection equipments**		Once a year	+++	Internal
Test protection cells and circuit breaker		Once a year	++	Internal
Leakage detection of the insulation oil, check liquid level and closing elements		Once a year	++	Internal
Painting damage detection (overheating indicator)		Once a year	++	Internal
Check the possible existence of **condensation or water infiltration** in the terminals box		Once a year	++	Internal
Infra-red detection of overheating cables		Once a year	++	
Assess the load profile for a typical operation duration by measuring currents and voltages				
Check the air circulation around transformers		Once a year	++	Internal
Test the powers, currents and voltages supplied to **detect possible overloads**		Once a year	++	
Oil analysis for immersed transformers (chromatography, insulation properties, water percentage, gas analysis Buchholz relay...), every two years for breathing transformers and every six years for non breathing transformers		Every two or six years	+	External
Measurements of winding and connections resistance		Once a year		
Insulation tests		Once a year		

Upgrades

In case of defective equipment or material, there are three different possible lines of action:

- repair the defective material,
- replace the defective material with an equivalent one available onsite,
- replace the defective material with a new one with higher energy efficiency.

In any case, a technical and economical analysis should be performed, taking into account the global cost, the standards or specific characteristics and the delivery or reparation duration. In general, the replacement of an old or defective standard equipment with a new one, more efficient, is cost effective and quick (standards equipments are easily available). On the other hand, for specific equipment or if in the past standards have changed, the repair option is usually the quickest and the most cost effective solution.

Description	Savings	Frequency	Feasibility	Skill required
Rewinding is generally a cost effective solution for non standards transformers or rotating machines			+	External
Replace tank joints				External
Replace the insulation liquid after tank cleaning				External
Replace old transformers with **high**	15 to 20% of			External

efficiency transformers	no-load losses			
Replace old (<1980) general low voltage table with new (>2000) ones (conductors length reduced by 40%)	Joule losses reduced by 30%			External
Select high efficient elements for general low voltage table, with low energy consumption (e.g. standards circuit breaker (20 W) and efficient (7 W). Such power reduction can also prevent the need for air conditioning				External
Replace old power inverters with new efficient inverters: the efficiency is higher and the power factor is enhanced by 10 to 15%				External
Add harmonics filters in case of poor power quality networks				external

Design and installation

Description	Savings	Frequency	Feasibility	Skill required
Select high efficiency transformers rather than standards transformers	15 to 20% of no-load losses		++	Internal
Make sure the transformer is correctly **cooled** if located in a small enclosed area		--	++	Internal
Choose natural convection cooled transformer (ONAN) rather than forced convection transformer (ONAF)			++	Internal
Gather non linear loads close to the transformer low voltage feeders		--	+	Internal
Contain non linear loads		--	+	Internal
Reduce the transformer short circuit voltage (or the impedance) / derate transformer		--	++	

For specific processes such as metallurgy, harmonics filters won't be sufficient enough; a global approach is therefore needed regarding the network design.

The assessment should, for each of the measures in previous tables, evaluate applicability and profitability. This might take a form similar to the following table.

Table "Assessment Results"

Energy saving measures	Specific proposed action	Estimated annual energy savings (1)	Change in annual O&M costs (2)	Additional investment cost (2)	Estimated payback time (months)
Operation					
…					
Maintenance					
…					
Upgrades					
…					
Design and new installations					

Legend

(1) When energy savings cannot be precisely measured (as is often the case), they can be estimated from the assessment results and generally accepted technical coefficients.

(2) Investment and O&M costs are estimates of changes in costs, with respect to what would have been spent without Partner commitment to the Motor Challenge. This may be, for instance: additional investment for higher performance equipment, increase/decrease in maintenance costs, associated savings from better quality or reliability, etc.

5. Action plan

Your company's Action Plan, as proposed in the form below, should mention:
- for the measures you have decided to implement: time scale for implementation,
- for the measures you have decided not to implement: the reasons.

The Action Plan is presented to the Commission. After approval, your organisation will be recognised as an MCP Partner.

Energy Savings Measures	Feasibility (1)	Specific Actions (2)	% Covered (3)	Time table (4)	Expected savings (5) (MWh/year)

Legend:

(1) **Feasibility.** Indicate obstacles to application by one or more of the following codes:

NA Not applicable for technical reasons
NP Not profitable
NC Not considered, because evaluation would be too expensive

If this field is left blank, the measure is considered to be both applicable and profitable.

(2) **Specific Actions.** Several specific actions may be adopted to implement one energy saving measure.

(3) **% Covered.** If the Partner's proposed commitment covers several transformers, this column should be used to indicate the proportion of the transformers for which the specific actions will be implemented. This can be evaluated according to the most convenient indicator: number of transformers; power; energy consumption. Specify the indicator used, as by: "%"; "%kW", %kWh". Specify the number of industrial sites, or factories involved.

(4) **Time table.** The time scale at which the action will be implemented. This might be a specific period or date, or might depend on some other action, for instance "When transformer is replaced", or "When paint shop is refurbished".

(5) **Expected savings** in MWh/year. This will often be an estimate, based on generally accepted practice.

6. Annual report

The Annual Report to the Commission specifies progress made in carrying out the Action Plan, and will comment on any new or amended initiatives. The following reporting form should be used with progressive updating on an annual basis. The two left hand columns are copied from the Partner's Action Plan as approved by the Commission.

Approved Action Plan		Annual report for year 20xx
Actions decided upon to implement energy savings measures	Agreed upon time scale for action	Progress on action, as percentage achieved, and comments where appropriate (1)
Action 1		
Action 2		
…		

(1) The percentage achieved could refer to an indicator such as the proportion of systems in the scope of the Action Plan for which the specific action has been completed.

Partners may find it useful to produce parts of the following Synthesis of the results of commitment to the Motor Challenge. They are invited (but not required) to submit the Synthesis to the Commission.

Annual report synthesis		
	Since commitment	This year
Percentage of actions in Action Plan completed		
Estimated total investment for Plan (000 EUR) (1)		
Estimated change in non energy O&M costs (000 EUR) (1)		
Estimated energy savings (MWh) (1)		
Electricity consumed compared to goods produced (000 kWh/Q-Prod.) (2)		

(1) See above, legend for Table "Assessment results"

(2) Q-Production is some relevant indicator of the volume of goods produced at the production site, expressed, for instance, in tones, yards, pieces, …