On-site Assessment of High Voltage Motors Insulation Operating in Oil Facilities

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Abstract. Thirteen motors rated at 13,8 kV and 2500 H. P. of capacity installed and operating in a critical Oil Pumping Plant, were evaluated on-site, to determine the insulation system condition and schedule a maintenance program. This on-site assessment was based on a non-invasive and non standardized ultra-wide band partial discharge technique developed. The results obtained allowed motors insulation system status classification, according to partial discharges measured on ground connection of the main cables of the motor, employing near field sensors. A traditional N-Q-Φ Partial Discharge pattern is obtained to facilitate motor insulation system problems identification. The results of this on-site motor assessment, during normal operation, and its application on maintenance programs are presented and discussed in the paper.

Key words:

High voltage motors, on-site Assessment, ultra wide band, partial discharge.

1. Introduction

The high voltage induction motor, up to 13,8 kV, is a equipment widely used in the Mexican oil industry. A sudden failure of the insulation system of this machine can result catastrophic, especially in dangerous classified areas. On the other hand, failures of motors insulation system have high economic impact by the time that involves the repair or replacement of the machine and the loss or interruption of oil pumping to refineries or load tankers process. Hence, it is necessary to ensure its operational continuity, through the timely detection of incipient failures emerging due to the electrical, chemical, mechanical and thermal stresses, which are being subjected during its operation[1].

The Mexican Oil Company is changing their motor maintenance strategies based on periods of time elapsed (preventive maintenance), toward the scheduled maintenance on the basis of the real status of the equipment (predictive maintenance). In order to sustain technically its maintenance programs, have embarked on the implementation of new techniques of on-line evaluation, which allows assess the operational status of the induction motors operating in nominal conditions.

In the last years the Mexican Electrical Research Institute (IIE), have been working in the development and implementation of diagnostic techniques for power electrical equipment, based on Partial Discharges (PD) measurements[2].

As it is well known, the Partial Discharges (PD) is a consequence associated to failures in high voltage motors, a high level of partial discharges in the machine, is an indication of problems in the insulation system, these problems over the time can evolve into a failure. Hence, the detection of PD is very important to know the motor condition [3][4][5].

In this article is presented and analyzed the results obtained from the application of an on-line evaluation technique for medium and high voltage motors, based on the measurement of Partial discharges (PD) in the ground connection of the main cables of the motor, employing near field sensors. This PD measurement approach utilizes ultra wide band (UWB) measuring techniques for proper PD detection and noise cancellation. Thirteen high voltage motors were evaluated on-site and on-line, these motors are currently operating at an oil pumping facility. All this motors are 20 years old and all have start up at full voltage. The obtained results allow to complement and modify the maintenance programs in accordance to the conditions of each assessed motor.

2. Assessed motors

Thirteen induction squirrel cage, horizontal motors, rated at 13,8 kV and 2500 H.P., installed and operating in a critical Oil Pumping Plant, were evaluated. It is important to mention that those motors are operating continuously, and off-line PD detection may take more than one shift and therefore it is considered an unacceptable outage, due to the large economical implication.

These motors have at least 20 years of operation and during this time, have been subjected to continuous starts and shutdowns. According to the literature, this type of operation, it may cause transient overvoltage that directly affects the windings of stator and transient currents which can cause damage to the rotors. Some of these motors have presented fails in its windings, so that they had been subjected to repairs.

The Figure 1 shows the electrical single diagram of the oil pumping facility where the assessed motors are installed. The Figure 2 shows an overview of this facility. The power supply to the motors is provided through insulated power cables, installed in trenches.

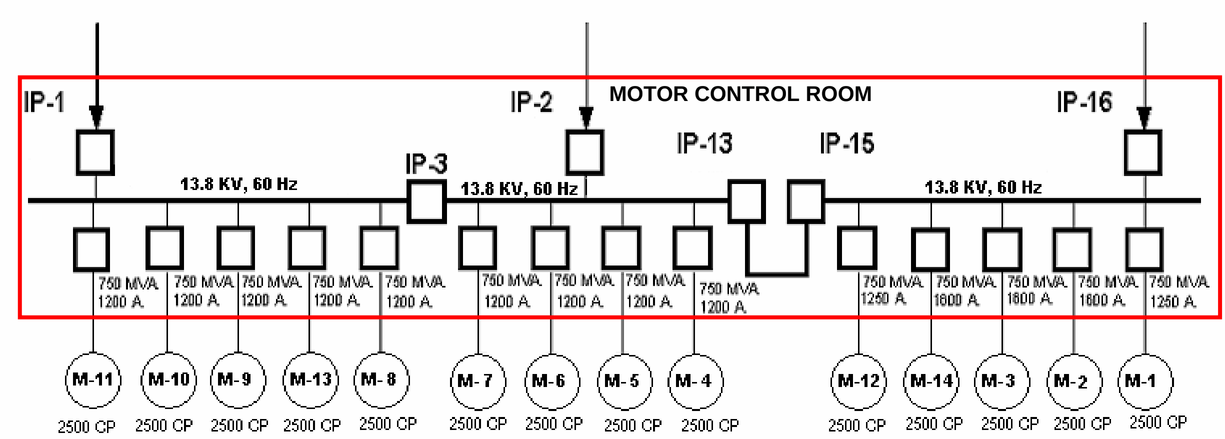

Fig. 1. Electrical single diagram of the assessed motors

Table I. Nameplate Data of assessed motors

NAMEPLATE DATA	
ID.	M-1 to M-14
H. P.	2500
PHASES	3
VOLTAGE	13,200 VOLTS
CURRENT	100 AMP
TYPE	TFLA
FRECUENCY	60 Hz
POLE NUMBER	2
ROTATION SPEED	3570 R.P.M.

Fig. 2. Overview of assessed motors

3. On-site assessment circuit set up

The Partial Discharge detection in motors based on ultra wide band techniques (UWB), is a not standardized method and its implementation on-site consider the following:

a) The measurement circuit must not be invasive, this is, It should interfere as little as possible with the normal operation of the motor.

b) The circuit must be inherently safe, given that it will be used in dangerous classified areas.

c) The circuit should be implemented with the motor primary circuit energized and operating at nominal conditions, to carry out on-line measurements.
The calibration of the circuit must be simple and safe.

d) The Partial Discharges results carried out must agree to the international standard practices.

The electrical circuit for the motor evaluation, based on ultra wide band techniques, is shown in Figure 3.

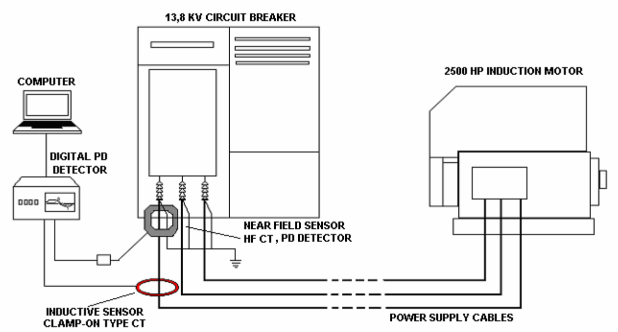

Fig. 3. Test circuit for high voltage motors PD detection.

The PD measurement was carried out placing a "clamp-on" Rogowski type sensor with a bandwidth of up to 40 MHz, in the main power cables of the motor at the breaker side, located in the motor control room. For the PD readings, conventional equipment for detecting partial discharges is used. This measurement equipment consists of an acquisition and signal processing unit. The obtained signals through the near field sensor are conditioned through a pre-amplifying unit, which changes the characteristics of measured signal of UWB to conventional for reading in a conventional detector. This detector displays the measurement in a PD type N-Q-Φ pattern [6]. The Figures 4 and 5 show the test circuit on-site physical implementation.

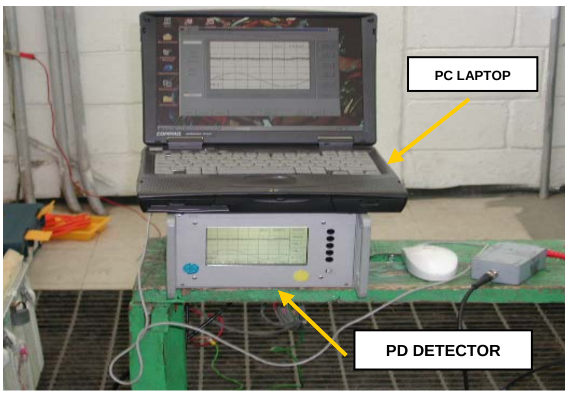

Fig. 4. Physical on-site Implementation of the test circuit (recording)

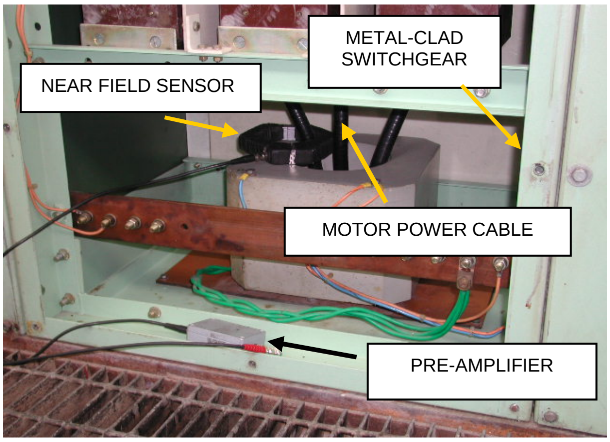

Fig. 5. Physical on-site Implementation of the test circuit (detection)

4. Results Analysis

This on-site assessment was based on a non standardized ultra-wide band partial discharge technique, because of this as a first step in the application of this technique, the results analyses are based on the criteria of the IERE (International Electrical Research Exchange) [7] shown in Table II. PD values are related to an indirect loop calibration and are used for classification and comparison purposes rather than to assess an absolute charge value in nano Coulombs.

The Table III, presents the results obtained from the assessment of the motors on-site. The measurement of PD was carried out in each phase of the thirteen motors tested. This table includes the obtained levels (nano-Coulombs) of partial discharges at each motor phase. The actual winding condition based on maintenance records is also included.

A high magnitude of PD means significant insulation deterioration, the ideal insulation is one that does not have PD activity, based on these premises it is possible to do a comparison between the evaluated motors, given that all have the same design, the same constructive characteristics and operate under the same load conditions.

Based on this, an immediate classification of evaluated motors based on dielectric conditions is established. This classification allows schedule, from the dielectric point of view, the inspection and maintenance activities.

The obtained results show, that identified M-14 motor, has the highest level of partial discharges (570 nC), while the M-1 has the lowest value (10 nC). The information obtained from the maintenance records, shown that both motors were repaired and their windings replaced. However, it appears that the quality of the motor winding M-14 repair was lower than that of the motor M-1, or that during normal operation at the motor M-14 have been initiated one or more deterioration mechanisms, which are causing a high level of PD.

Table II. IERE criteria for the insulation system evaluation based on measured PD magnitude [7]

Q máx (nC) Measured	Insulation System Condition
≤ 10	Good condition
> 10 ≤ 30	Continue at Operation, observe
> 30	Inspection required as soon as possible, identify PD cause.

Table III. PD level measured in assessed motors

MOTOR ID.	PHASE	PD MAGNITUDE (Qmax Nc)	ACTUAL WINDING STATUS
M-1	A	10	Repaired
	B	24	
	C	14	
M-2	**A**	**120**	No repaired
	B	70	
	C	70	
M-3	A	18	Repaired
	B	36	
	C	16	
M-4	A	36	No repaired
	B	23	
	C	25	
M-5	**A**	**100**	Repaired
	B	22	
	C	28	
M-7	A	28	No repaired
	B	15	
	C	20	
M-8	A	36	Repaired
	B	36	
	C	48	
M-9	A	75	No repaired
	B	75	
	C	**112**	
M-10	A	36	Repaired
	B	48	
	C	48	
M-11	A	30	Repaired
	B	30	
	C	48	
M-12	A	27	No repaired
	B	26	
	C	36	
M-13	A	60	No repaired
	B	**120**	
	C	60	
M-14	**A**	**180**	Repaired
	B	**180**	
	C	**570**	

The Table IV, shows the classification of the evaluated motors in accordance with the magnitude of PD measured in its windings, and taking as a reference the criterion mentioned in Table II. The status of the motors were established as "GOOD," "OBSERVE" and "INSPECTION REQUIRED". This classification allows, to establish the priority to carry out the inspection and maintenance of the evaluated motors.

Another assessment objective is to allow the identification of deterioration mechanisms in the evaluated motors. These mechanisms are identified by the interpretation of the Partial Discharges patterns, obtained from the measurement.

Table IV. Motors classification based on PD magnitude measured

MOTOR ID.	INSPECTION AND MAINTENANCE PRIORITY	PHASES	Qmax nC	CLASSIFICATION
M-14	IMMEDIATELY	A	180	INSPECTION REQUIRED
		B	180	
		C	570	
M-9	1	A	75	INSPECTION REQUIRED
		B	75	
		C	112	
M-2	1	A	70	INSPECTION REQUIRED
		B	70	
		C	120	
M-13	1	A	60	INSPECTION REQUIRED
		B	120	
		C	60	
M-5	1	A	22	INSPECTION REQUIRED
		B	28	
		C	100	
M-10	2	A	36	OBSERVE
		B	48	
		C	48	
M-8	2	A	36	OBSERVE
		B	36	
		C	48	
M-11	2	A	30	OBSERVE
		B	30	
		C	48	
M-12	3	A	27	GOOD
		B	26	
		C	36	
M-4	3	A	23	GOOD
		B	25	
		C	36	
M-3	3	A	16	GOOD
		B	18	
		C	36	
M-7	3	A	15	GOOD
		B	20	
		C	28	
M-1	3	A	10	GOOD
		B	14	
		C	24	

Because of lack of specific technical references about on-line and on-site motor assessment based on partial discharge using ultra wide band techniques, to compare with obtained results, the PD patterns obtained were compared with those included in the reference generated by the group 21.03 of CIGRE, "Recognition of Discharges" [8]. Of this comparison it is concluded the following:

A. Motors in good conditions

The PD pattern shown in Figure 6 shows the PD activity map obtained in phase 1 of motor M-1. At this phase was measured a maximum charge of 10 nC, which was the lowest PD level measured on-site.

This value indicates that the motor insulation system is in good conditions and can operate normally. Other assessed motors whose insulation are on acceptable conditions to continue in operation, were motors M-3, M-4, M- 7 and M-12.

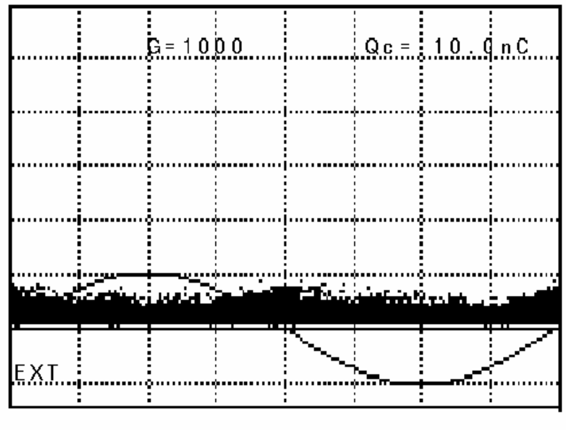

Fig. 6. Motor M-1 PD pattern, 10 nC Max.

B. Motors with slot partial discharges problem

The PD pattern shown in Figure 7, shows the PD activity map obtained in phase 3 of motor M-14. It distinguishes that PD in the negative semi cycle are greater than those of positive in 5:1 relationship. This pattern and the high level of DP (570 nC) according to [8], is typical of the activity of slot partial discharges (PD between coil surface and stator core laminations). Phases 1 and 2 also presented this behavior, although with reduced levels of 180 nC. This mechanism of deterioration is the most severe, from the electrical insulation point of view; the partial discharges erode the main insulation decreasing its lifetime.

The recorded PD magnitude in this motor is extremely high. Given that this type of PD can lead to the failure of the insulation, its immediate shut down to test its windings and avoid a fault was recommended.

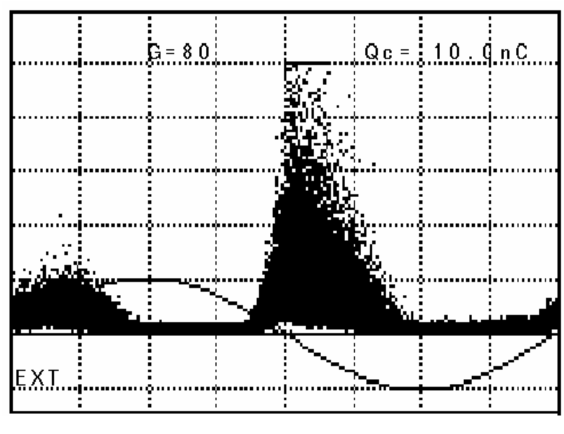

Fig. 7. Motor M-14 PD pattern, 570 nC Max.

C. Motors with field graduation problems

The Figure 8, shows the pattern of the PD activity map obtained in phase 2 of motor M-13. This PD pattern is different to that obtained in the motor M-14. The partial discharges have similar magnitudes in both semi cycles, so it is clear that this is a different deterioration mechanism.

This PD pattern was recorded in the motors M-9 and M-13 with similar magnitudes 120 nC in one phase of each motor. Even when these motors presented values of similar PD, its maintenance record is different, the motor M-9 keeps its original winding, manufactured 20 years ago, while the engine M-13 has a recently repaired winding.

In both motors the pollution deposited in the end windings can be the PD cause; the pollution avoids the correct graduation of electric field. Another cause may be the deterioration or incorrect stress grading coating application (in the case of the repaired motor). In the case of the Motor M-9, the high magnitude of partial discharges can be caused by the separation of insulation tapes. These motors are recommended for inspection and end winding clean up or reapplications of stress grading coating.

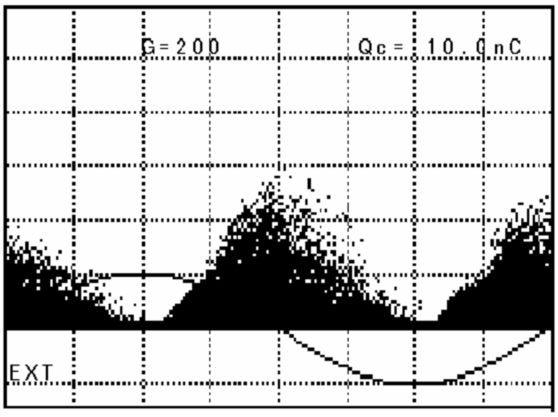

Fig. 8. Motor M-13 PD pattern 120 nC

D. Motors with specific problems

The PD magnitude of phases B and C of motor M-5 was 22 and 28 nC respectively. This result indicates that the insulation of these phases is in good conditions, the phase A have a PD magnitude of 100 nC, indicating an abnormal insulation condition.

It is difficult that a phase have bigger deterioration than the other two, because the windings are under the same operation stress. The phase A PD high activity must have as origin a specific fault, which is necessary to determine its origin.

5. Conclusion

Measurements carried out for the motors assessment, have the sensitivity to allow an insulation system classification of similar motors, according to the PD magnitude measured. This is seen in the measured results, ranging from a minimum PD of 10 nC until a maximum PD of 570 nC, which implies a motor with a larger deterioration than the other.

The comparison of the PD patterns obtained and PD reference patterns was found coincidence between the two, relate to the mechanisms of deterioration that cause it.

The ultra-wide band partial discharge technique for high voltage motors insulation system assessment, used at oil facilities, has the advantage to be non-invasive, with high sensitivity, selectivity and ease of use. Based on the results we consider the employed technique a diagnostic tool that can be used to improve the predictive maintenance programs.

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