STANDARD OPERATING PROCEDURE
FOR

MEGGER TESTING OF NON-SUBMERSIBLE PUMP STATION MOTORS

(24 February 2022)

The purpose of this SOP is to provide direction for the consistency of performing and documenting what is commonly known as "Megger Testing", but what is more accurately identified as motor winding measurements. Federal regulation 33 CFR 208.10(f)(1) requires that the insulation of motor windings be tested at intervals not to exceed one year. Routinely documenting and plotting the test results of this procedure can help identify the degree and rate of degradation of the motor winding insulation to estimate its remaining useful life and when the motor should be rewound.

MOTOR WINDING MEASUREMENTS

These Motor Winding Test Procedures are based upon the provisions of IEEE 43-2000(R2006), "IEEE Recommended Practice for Testing Electrical Insulation Resistance of Rotating Machinery", U.S. Bureau of Reclamation Facilities Instructions, Standards, and Techniques, Volume 3-1, "Testing Solid Insulation of Electrical Equipment", December 1991, and Electric Power Research Institute "Electric Motor Predictive Maintenance, Draft Guidelines" TR-108773-V1.

The voltages applied during insulation resistance testing shall be in accordance with the recommendations of IEEE 43, Table 1, "Guidelines for DC voltages to be applied during insulation resistance test", as indicated below:

Winding rated voltage (V)a	Insulation resistance test direct voltage (V)
<1000	500
1000–2500	500–1000
2501–5000	1000–2500
5001–12 000	2500–5000
>12 000	5000–10 000

[a] Rated line-to-line voltage for three-phase ac machines, line-to-ground voltage for single-phase machines, and rated direct voltage for dc machines or field windings.

Conditions for Testing

It is essential for obtaining accurate testing data that both the motors be offline (including any winding heaters) for at least one hour and the windings be at least 5ºC (9ºF) above the dew point temperature prior to and during the tests. Record the relative humidity and dew point by a direct-reading digital meter or by using the wet and dry bulb temperatures with a psychrometric chart/table. Determine the motor winding temperature by averaging several measurements at various locations both vertical and horizontally around the motor case.

Test Preparation

When possible, all testing should be performed at the Motor Control Center or at the control gear (e.g., combination starter disconnect) for the individual motors; where not possible, testing shall be performed at the motor leads. Testing is to be performed on the motor feeder cables and motor concurrently. When the test results are questionable, disconnect all cables and retest from the motor leads. When testing to distinguish between weak cable insulation and weak motor winding insulation, or when separate measurements are required, the feeder cables must be disconnected from the motor leads and the cables and the motor tested separately according to the following steps.

1) Ensure that all appropriate safety blocking is in place, and that, as a minimum, the site's lockout/tagout procedures are followed.

2) Visually inspect the motor under test, and its control gear, for signs of obvious damage and document these observations on the test report.

3) Verify and document the operational status of the motor under test, associated controls, associated metering, associated indicators and displays, and associated sensors.

4) Record/verify all nameplate data.

5) Isolate any motor power factor or surge capacitors, and surge arrestors.

6) Short out and ground all winding resistance temperature detectors (RTDs) and current transformers.

7) Perform all of the test equipment self-diagnostics and ensure the integrity of the lead insulation and the continuity of the leads and connections.

Motor Winding DC Resistance Measurements

1) Short and ground all windings for one minute.

2) Remove the ground from the windings to be tested.

3) Connect a Kelvin Bridge, Wheatstone Bridge, or Digital Low Resistance Ohmmeter (DLRO) across the terminals to measure the resistance of the motor windings.

4) Record the motor winding temperature.

5) Record the winding resistance on the data sheet.

6) Disconnect the Bridge or DLRO from the winding terminals.

7) Repeat Steps 2 through 6 as necessary for the remaining windings.

8) Correct the measured resistances to 40°C using the following formula, given in IEEE 112-2004, "IEEE Standard Test Procedure for Polyphase Induction Motors and Generators", and enter the values in the Motor Testing Record sheet:

$$R_b = R_a \times \left(\frac{t_b + k_1}{T_a + k_1} \right)$$

R_a = the known value of winding resistance, in ohms, at temperature t_a,
t_a = the temperature, in °C, of winding when the resistance R_a was measured,
t_b = the temperature, in °C, to which the resistance is to be corrected,
R_b = the winding resistance, in ohms, corrected to the temperature t_b,
k_1 = 234.5 for 100-percent IACS conductivity copper, or 225 for aluminum, based on a volume conductivity of 62%

For copper windings, corrected to 40ºC, the formula reduces to:

$$R_b = R_a \times \left(\frac{274.5}{T_a + 234.5} \right)$$

R_b = Corrected Resistance at 40°C
R_a = Measured Resistance
T_a = Measured Temperature in Centigrade

Note: This formula will yield slight variations if the motor cable temperature is different than the motor temperature, or if the motor cable is not copper.

Insulation Resistance Test Preparation

1) Determine the minimum acceptable resistance at 40ºC. Where Insulation Resistance Curves have been provided for the individual motors, locate the point at which the curve crosses the 40ºC vertical line and read the resistance value from the left or right edge of the chart. Where curves have not been provided, determine the minimum acceptable resistance at 40ºC using the table below (from Table 3 of IEEE 43):

Recommended minimum insulation resistance values (MΩ) at 40 °C

Minimum insulation resistance	Test specimen(s)
$IR_{1\ min} = kV + 1$	• Most windings made before about 1970 • All field windings • Others not described in the cells below
$IR_{1\ min} = 100$	Most DC armature and AC windings built after about 1970 (formwound coils)
$IR_{1\ min} = 5$	Most machines with random-wound stator coils and formwound coils rated below 1 kV

- $IR_{1\ min}$ is the recommended minimum insulation resistance, in megohms, at 40 °C of the entire machine winding
- kV is the rated machine terminal to terminal voltage, in rms kV

2) Record the minimum acceptable resistance at 40ºC on the Motor Testing Record sheet.

3) Short all three phases together

4) Using a Volt-Ohm Meter, measure the motor insulation resistance to frame/ground for one minute to determine if it exceeds the minimum value recorded in Step 2. If it exceeds the value recorded in Step 2, proceed with the Insulation Resistance Test below; if it does not, stop further testing and inform your Levee Safety Point of Contact (LSPOC) of the issue.

Insulation Resistance Test

1) Apply the test voltage determined from Table 1 of IEEE 43 on the test sheet form to the windings.

2) Record the motor insulation resistance to ground at the intervals indicated on the Motor Testing Record sheet.

3) Record whether the test was performed with or without cables on the Motor Testing Record sheet.

4) If the test equipment is equipped with internal discharge resistors, permit the voltage to fall to zero volts. If the test equipment is not equipped with internal discharge resistors, ground the windings through either the resistor that is provided with the test equipment, or a resistor that is sized to keep the drainage current below 0.001 amps, until the

residual voltage falls to zero. Once the residual voltage has fallen to zero, a direct connection between ground and the windings should be applied. Continue to ground the windings for a period equal to four times the test time, or one hour, whichever is greater.

5) Disconnect the test equipment once a direct connection between the windings and ground has been established.

6) Correct the resistance to 40°C using the correction factor (K_t) determined from the motor insulation resistance curves, or from the following equation:

$$K_t = (0.5)^{(40-t)/10}$$

7) Calculate the Polarization Index (PI). For motors with alsphaltic mica winding insulation, the PI is calculated by dividing the 10-minute reading by the 1-minute reading. For motors with epoxy or polyester winding insulation, the PI is calculated by dividing the 5-minute reading by the 1-minute reading. If the winding insulation resistance readings exceeded the maximum range of the meter before the five-minute time had been reached, calculate the Dielectric Absorption Ratio. Record on the Motor Testing Record sheet.

Post-Testing Restoration

1) Remove shorting and grounding connections from winding RTDs and current transformers.

2) Reconnect any motor power factor or surge capacitors, and surge arrestors that were isolated for testing purposes.

3) Verify and document that the operational status of the motor under test, associated controls, associated metering, associated indicators and displays, and associated sensors is restored to the pre-test condition.

One-Minute Insulation Resistance Interpretation

The one-minute insulation resistance (IR1), corrected to 40°C, is the value that is used to trend the long-term condition of the insulation.

The minimum acceptable one-minute insulation resistance (IR1) depends on the stator winding insulation material. If the IR1 corrected to 40°C is greater than (kV+1) megohms, then this is acceptable for asphaltic mica windings. If the corrected IR1 is greater than approximately 100 megohms (for any voltage class), then this is acceptable for epoxy mica and polyester mica windings. Readings lower than these thresholds indicate that the winding has been contaminated with a partly conductive film of oil or moisture, or that the winding insulation has cracked, exposing the copper conductors. The winding should be dried, cleaned, or at least inspected, before being returned to service.

If the insulation resistance test has been used over the years, and the readings have always been made at temperatures above the dew point, then the trend in IR1 may indicate that gradual deterioration from pollution or moisture absorption is occurring. Increased deterioration is indicated by a decrease in IR1 over time.

Dielectric Absorption Ratio/Polarization Index Interpretation.

Dielectric Absorption Ratio:
The dielectric absorption ratio should only be used for insulation systems that start with a very high resistance value (>1500 megohms) and very quickly reach values in excess of 2,000 megohms. Refer to Step 7 of the Insulation Resistance Test for more information

Polarization Index:
For asphaltic mica windings and older (pre-1970) polyester mica windings, the polarization index can be interpreted as follows:

PI<1: The winding is very deteriorated by the absorption of moisture; and/or, the end windings have been polluted with partly conductive moisture, oil or other contaminants.

1<PI<2: Some deterioration is occurring due to moisture or pollution.

2<PI<7: The winding is clean and dry.

PI>7: The insulation may be brittle due to thermal aging of the insulation.

For modern epoxy and polyester windings, the PI can be interpreted as follows:

PI<1: It is likely that moisture and dirt are present within the windings, and the insulation effectiveness has been compromised

1<PI<2: Some contamination of the winding by moisture or oil is present.

P>2: The winding is clean and dry.

If the IR1 is greater than 1,000 megohms when testing an epoxy or polyester mica winding, many users may not perform the 10-minute test since it is clear the winding is clean and dry.

A Motor Testing Record sheet is attached and all field should be filled out in its entirety, and two helpful EXCEL spreadsheets (Temperature Correction Calculator.xlsx and Motor Winding Insulation (Megger) Testing Tracking Sheet.xlsx) can be provide by your District LSPOC upon request. The temperature correction factor calculator should be used to adjust insulation and winding resistance values to 40°C per the testing instructions. The motor winding insulation (megger) testing tracking sheet should be used to track each motor's insulation over time so trending plots can be generated for IR1, polarization index, and dielectric absorption ratio to help anticipate refurbishment or replacement scheduling.

MOTOR TESTING RECORD Date ________________

Apparatus
Description __________________ Year of Mfr. ________ Insulation Class/Type __________

Rated Voltage _______________ Single or Three Phase _____________ Rating ____________HP/kW

Minimum Acceptable
Insulation Resistance _______________ From: IEEE 43, Table 3 or Curve? ____________

Hours Since Motor Shutdown _______________

Test Conditions:

Ambient Temperature °F ______ Wet Bulb Temperature °F _______ Relative Humidity % ______

Dew Point Temperature °F ________

Weather ____

Winding Temperature °F _______________ Obtained how? _______________________________

WINDING RESISTANCE

Instrument
Make and Model __________________

Calibration
Date ____________

Resistance
Range ____________

Resistance (Ohms)

	A-B	A-C	B-C
Reading			
Corrected			

With Cables ______ without Cables _____

INSULATION RESISTANCE & DIELECTRIC ABSORPTION RATIO/POLARIZATION INDEX

Instrument
Make and Model __________________

Calibration
Date __________

Resistance
Range _____________

Applied
Voltage ______

Test Data:

MINUTES	0.25	0.5	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
Reading												
Correction												

Winding Grounding Time __________________

Dielectric Absorption Ratio ($R_1/R_{0.5}$) ___________

Polarization Index (Age specific – see IR Test Step 7 - R_{10}/R_1 or R_5/R_1) _______________

Remarks: ____

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Tested by _____________________________________