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Insulation system modeling of motor circuits

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***Abstract* — Over the last century as electrical motor testing became more prevalent in industry, little research has been published on computer simulations insulation systems of motor circuits. In this paper, we will present summary results of simulating insulation systems of motors and their associated cabling systems (i.e. the motor circuit). Summary results of the difference in measurements performed on isolated cables and motors as well as when they are connected will be presented. We will also discuss how the standard insulation model may be applied to all types of insulation systems including cables, transformers, etc.**

***Keywords* — Modeling; insulation; insulation system; insulation resistance profile; motor circuit**

I. Introduction

In the last few decades, much work has been done on insulation systems and measurements. However, little work has been done with computer simulations of insulation systems to model their behavior under various conditions. Even less research has been pursued on modeling the system, i.e. with the cables and motors connected together. In theory, by paralleling individual models of the power cable and the motor, one should arrive at a model that would represent the combined motor circuit. In the field this would represent motor circuit testing performed at the Motor Control Center (MCC), the physical location of the testing at most industrial plants (see Figure 1).

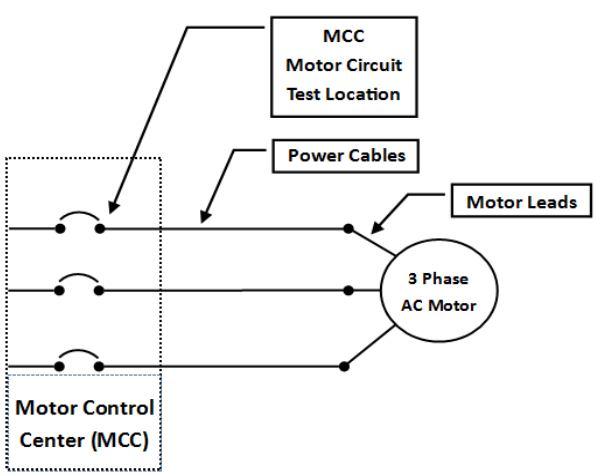

Fig. 1. Motor Circuit Block Diagram.

In this paper, we will use the insulation system model found in IEEE Std. 43-2013 to combine individual simulations of a power cable and motor. We will present summary results of the simulation of the combination of motor and cable models.

II. Modeling

Using an accurate real-world model, effects of various conditions such as moisture, contamination, and embrittlement (aging) have on the insulation system may be studied. Should an effective method of modeling be established, effects of various design parameters may be studied prior to laboratory experimentation.

A. Past Research

In previous papers we've studied the insulation system "base model" used in IEEE 43-2013 and how it applied in various situations such as moisture and contamination (Figure 2). Our research found that for practical applications of the base model, only 3 absorption current branches would be needed for most applications. To model contamination we found that "noise" sources (ideally white noise) would need to be added to the base model to properly simulate contamination.

B. Limitations of the Model

The limitations of the model is that it starts with actual test measurements. From these test measurements a simulation model is developed using inferred values based on actual measurements taken. Thus, the modeling process is backwards with respect to the ideal way simulation models are generally performed. In the typical modeling process, one first derives a simulation model and then based on the results of the model a prototype can be built using the model as a guideline. It should be noted that in this work, the opposite approach was taken, using measurements from a real motor/cable system to generate the model.

C. Modeling Process

Referring to Figure 2, to arrive at a model, one must review the actual measurements of the insulation system. To start, take the Capacitance to Ground (CTG) measurement and enter that as the Geometric Capacitance (C1) in the model. Using the overall insulation resistance, a value approximately that of the final overall Resistance to Ground (RTG) is chosen for the leakage current branch (R2). The conduction current branch

(R3) is negligible, so a much higher value than that of R2 is usually chosen. The absorption branches (R4-R6 and C2-C4) are the primary drivers of the overall Insulation Resistance Profile (IRP) so they have to be manipulated to shape the simulation graph such that it overlays the IRP of the actual measurements.

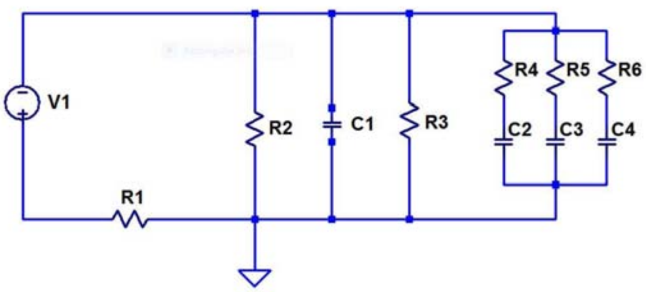

Fig. 2. Insulation System Base Model.

III. Circuit Assessment

In this paper, we are simulating the motor circuit of a 4160V, 500HP Induced Draft (ID) fan at a power plant. Insulation Resistance Profile (IRP) measurements were performed at 2500VDC from windings/cables to ground at the MCC of the motor circuit. Upon review of the results, we saw a low insulation resistance condition. To troubleshoot the situation, we de-terminated (removed) the cables from the motor and performed insulation testing on the motor itself and then the cables themselves separately. Note – we shorted all three cables together prior to applying the Insulation Resistance Test. Review of the data collected indicated the insulation system of the motor itself is in good condition, however, the insulation system of the cables was below the recommended values for operation. Thus, the power plant was informed they should replace the cables prior to returning the unit to service.

A. Model of the Cables

Our field measurements showed a CTG value of 92 nF so we used that value for C1. Reviewing our actual insulation resistance measurements, we found the final value to be approximately 140 Megohms. So we started with 140 Megohms for R2. We then started manipulating the values in the absorption branches to shape the profile to that of the actual measurements. After some trial and error, we arrived at the model as shown in Figure 4.

B. Model of the Motor

Our field measurements showed a CTG value of 60 nF so we used that value for C1. Reviewing our actual insulation resistance measurements, we found the final value to be approximately 3000 Megohms. So we started with 3000 Megohms for R2. We then started manipulating the values in the absorption branches to shape the profile to that of the actual measurements. After some trial and error, we arrived at the model as shown in Figure 6.

IV. Results of Model

We found that our derived models closely represented the actual test measurements of the cables and motor as tested separately. This close representation of actual test measurements suggested that when the models were combined, the resulting model should closely represent the actual measurements taken at the MCC. However, when we combined the individual models, we found the simulation did not match actual test measurements.

A. Model Results

Figure 3 shows the original test data of each insulation resistance measurement – motor only, cable only, and motor with cable connected (motor + cable). As previously mentioned, the overall insulation resistance of the cables themselves was approximately 140 Megohms, the motor itself was approximately 3000 Megohms, and the motor with the cables connected was approximately 55 Megohms.

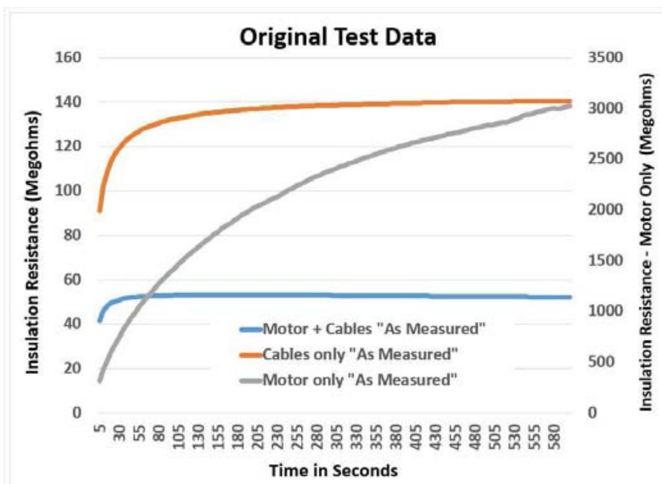

Fig. 3. Original Test Data.

Figure 4 shows the circuit used to perform the simulation of the insulation resistance of the cables only.

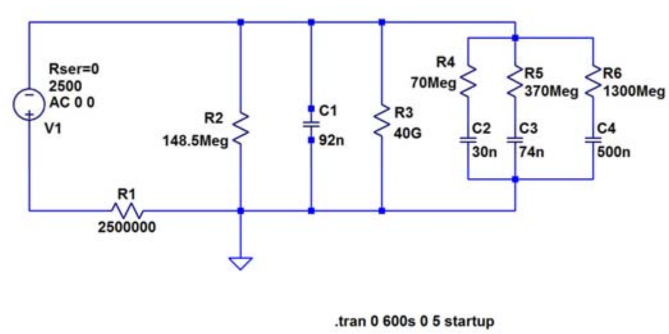

Fig. 4. Cables Only Simulation Circuit.

Figure 5 shows the comparison of the cables only circuit simulation to that of the actual test data. There appears to be very good correlation between the simulation and the “as measured” results.

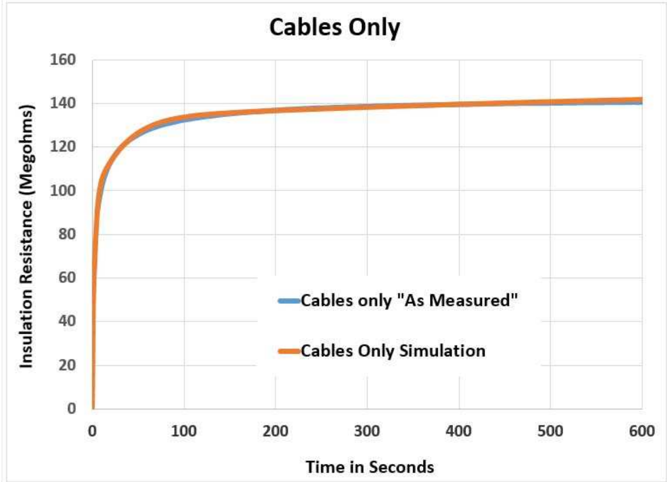

Fig. 5. Cables Only Simulation Graph.

Figure 6 shows the circuit used to perform the simulation of the insulation resistance of the motor only.

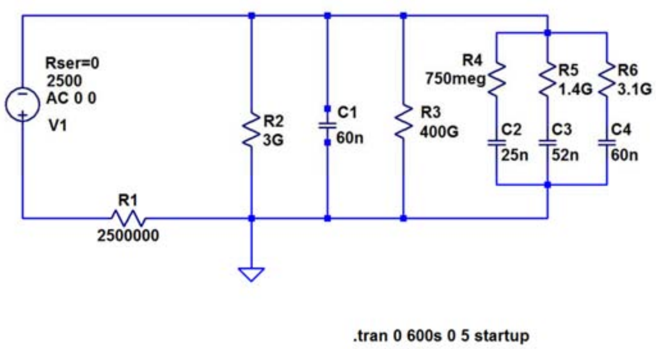

Fig. 6. Motor Only Simulation Circuit.

Figure 7 shows the comparison of the motor circuit simulation to that of the actual test data. With the exception of the last 75 seconds, the simulation overlaid the “as measured” results fairly well.

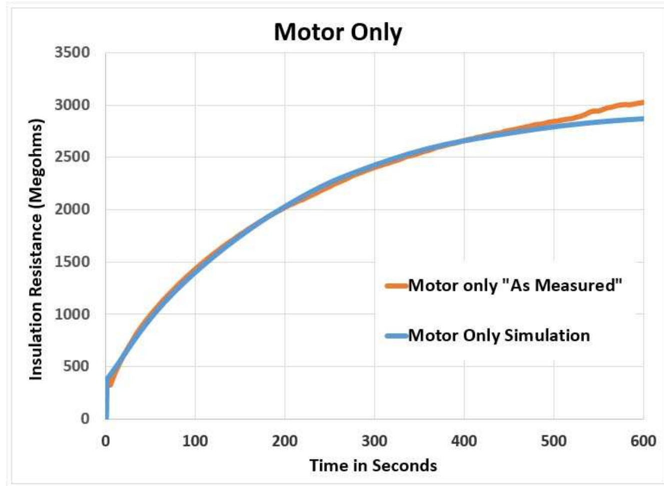

Fig. 7. Motor Only Simulation Graph.

Figure 8 shows the circuit used to perform the simulation of the insulation resistance of the motor and cables combined. To arrive at this model we paralleled the model from the motor circuit with that of the cable only model with no changes in any values of any components. Theoretically, this model should accurately represent actual test measurements of the motor circuit performed at the MCC.

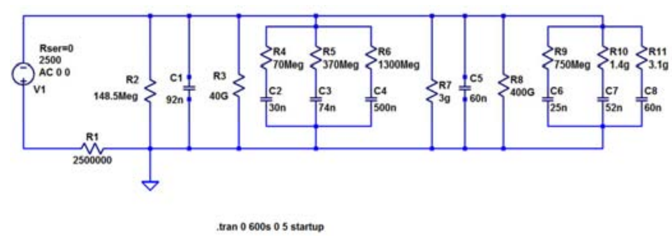

Fig. 8. Motor + Cables Simulation Circuit.

Figure 9 shows the results of the motor circuit simulation results as compared to the “as measured” results.

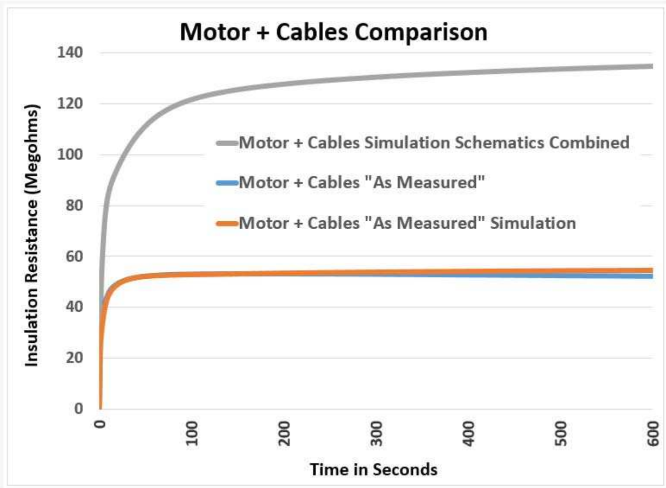

Fig. 9. Motor + Cables Simulation Graph.

B. Success of Model

The individual models of the motor and the cables themselves were very close to the original test data. This close representation to the actual test data suggested our models of the motor and the cables were fairly robust.

C. Limitations of Model

When we combined the individual models of the cable and the motor and ran simulations on them, the results did not match the real world "as measured" results. As shown in Figure 8, real world measurements showed a final insulation resistance value of approximately 55 Megohms whereas, the combined simulation model showed a final insulation resistance value of approximately 140 Megohms. Looking at the individual leakage current components (resistors R2 and R7), we find the parallel combination of them only drops the overall leakage resistance down to approximately 142 Megohms instead of a value near 55 Megohms which would be required for the overall insulation resistance to be approximately that of the actual measurements as seen in Figure 3. Thus, immediately, there is a significant discrepancy we have not been able to solve at this point.

OBSERVATIONS

When modeling cables, we found that the geometric capacitance had little effect on the overall Insulation Resistance Profile. The primary drivers of the "shape" of the profile were the Absorption current branches. This makes sense since there is typically a significant amount of insulation around the cables which takes a long time to polarize. It's this polarization that appears to be "capacitance" that result in long time periods to "charge" the cable during the Insulation Resistance test.

This paper is based only on one set of actual field measurements. Further modeling should be performed on actual field tests to determine whether the discrepancy we saw with these simulations would be consistent in other simulations of combined systems. Any discrepancies should be studied to evaluate what may be causing them.

We have shown the base model to be robust in its application to a singular insulation system not only in this paper, but, also in our previous work. However, we feel to be wholly robust, the model must stand on its own and in combined circuits such as a cable attached to a motor. We suggest further study to determine how robust the base model is in combinatorial types of situations.

After further study of combined models, and given the assumption the base model is robust for combined situations, we would theorize application of this type of simulation could be performed on any type of insulation system including transformers, motors, or any other type of insulation system with little modification made to the base model.

There are several benefits of monitoring cable insulation along with the motor insulation. One benefit is the user doesn't have to disconnect the motor from the system. This reduces the amount of effort needed to perform offline testing. Another benefit of monitoring both the motor and cable insulation systems together from a trending perspective is a user may see conditions conducive to failure such as at the connection points themselves that they would not see if they were testing them separately.

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