1976

Effect of Circuit Parameter Changes on Motor Protector Interrupting Capability

L. E. Cooper

EFFECT OF CIRCUIT PARAMETER CHANGES ON MOTOR PROTECTOR INTERRUPTING CAPABILITY

Lawrence E.Cooper, Manager
Design Engineering
Motor Controls Department
Texas Instruments Inc.
Attleboro, Mass.

INTRODUCTION

Users of line break motor protectors for the convenience of production and bench testing, sometimes employ test methods different from the actual application to verify the installation and that the protector has the correct response to locked rotor current. This paper will call attention to problems that may be created by these test methods which result in either failure or concealed damage to the line break motor protector.

These problems are invariably caused by changing one or more of the circuit parameters of line voltage, current or power factor from those of the actual application. Unless careful analysis of the effect of these changes is made, destructive arcing may result at the contacts of the protector. To develop an appreciation for the effect of changing these parameters during testing we must understand the mechanism of interrupting an AC motor load by contact opening.

CONTACT INTERRUPTION OF AN AC CIRCUIT

When an AC circuit is interrupted by contacts, advantage is taken of the fact that the current passes through zero twice each cycle. It would be ideal if we could insure that the protector contacts opened instantaneously at exactly zero current as no energy would be dissipated at the contacts and the dielectric strength of the contact gap would prevent restriking of the arc. In actuality, however, the contacts open at other than zero current. The open contacts continue to carry the circuit current in a burning arc until the next current zero takes place. At current zero the arc extinguishes, and the hot contact gap plasma must rapidly cool and deionize at a rapid enough rate to withstand the returning voltage across the open contacts without restriking the arc. This race between buildup of contact gap dielectric strength and the returning line and transient voltage must be won to prevent restriking the arc at the contacts. Certain circuit parameter changes may increase the frequency of arc restriking. This will result in a reduction of the protector life by accelerating contact erosion, and in some cases, may cause an immediate failure by continuous arc restriking.

FACTORS AFFECTING ARC RESTRIKING

There are many factors that enter into the complex problem of preventing an arc from restriking. These can be divided into two groups.

The first group of factors are those that affect the rate of increasing dielectric strength in the contact gap. With the exception of the magnitude of the load current which determines the ionization state of the contact gap, these factors are primarily controlled by the design of the protector. Following are the major protector characteristics that affect this aspect of the arcing.

Contact geometry	Field forces on the arc
Contact material	Materials impinged on by the arc
Contact opening speed	Atmosphere
Contact bounce on opening	Rate of contact cycling

The second group of factors are those that affect the rate of returning voltage across the gap.

Line voltage	Type of inductance
Power factor	Circuit capacitance

Since we are primarily concerned with changes in circuit parameters in this discussion, we will concentrate on the effect of the current magnitude and the factors in this second group.

Typical oscillagraph traces of the voltage across the protector contacts and the load current for resistive and inductive circuits are described next. These will allow evaluation of arc energy and the potential for restrike.

RESISTIVE CIRCUIT INTERRUPTION

Figure 1. is a drawing of a typical oscillograph trace showing contact interruption of a 100 ampere, 240 volt, 60 hertz, resistive load by a snap action protector. Both the circuit current (i) through the contacts and the voltage across the contacts (e) are shown. At t_0, current is flowing through the contacts and the voltage across the contacts is less than 0.1 volts. At t_1 the contacts open within 100 microseconds creating an arc across the contacts which burns at approximately 15 volts. The introduction of arc burning voltage of 15 volts into the circuit subtracts from the load voltage; but its value is small and the reduction in circuit current would be difficult to see on the trace shown. The arc will burn until the current approaches zero at t_2.

RESISTIVE CIRCUIT INTERRUPTION - 60 HERTZ
CURRENT AND VOLTAGE VERSUS TIME

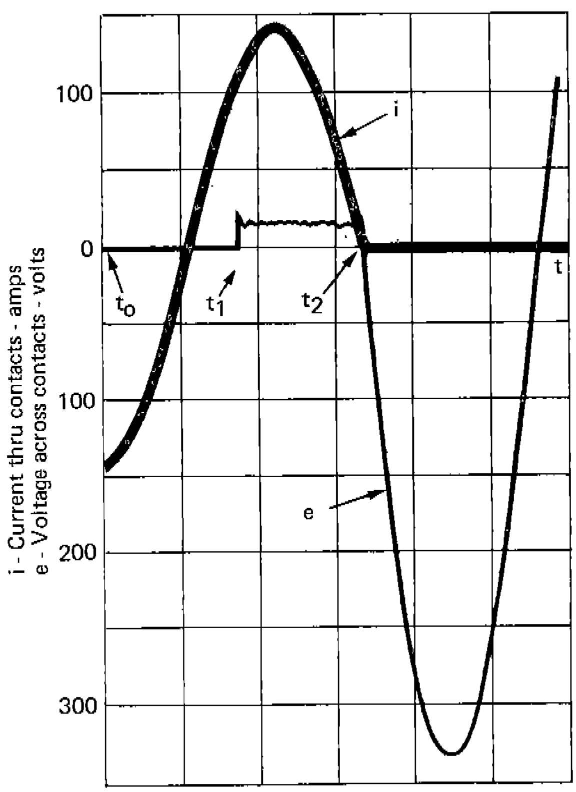

Figure 1

Just before current zero, when the current and line voltage can no longer support arcing, the arc extinguishes and the voltage across the contact gap becomes line voltage. With zero current flow, the contact gap begins to increase its dielectric strength by the cooling and deionization of the residual gases in the gap. As long as the rate of increasing dielectric strength exceeds the returning line voltage across the gap the arc will not restrike.

The energy dissipated in the arc can be calculated by the following equation.

$$W = \int_{t_1}^{t_2} eidt$$

Where: W = Energy in joules
e = Voltage across contact gap during arcing
i = Arc current
t_1= Time of arc initiation
t_2= Time of arc extinction

Since the opening of the protector contacts is random relative to the phase of the current through the contacts, the energy dissipated in the arc for particular contact opening will vary. For this circuit, the arc energy varies from zero to 5.6 joules with an average arc energy of 2.8 joules over the cycle life of the protector.

It is interesting to note that the arc voltage is essentially constant and independent of current. Because of this, the only factors affecting the energy dissipated in a single non-restriking arc are the magnitude of the current and the random point of contact opening.

Let's now consider the interruption of an inductive motor circuit.

MOTOR CIRCUIT INTERRUPTION

Figure 2. is a drawing of a typical oscillograph trace showing contact interruption of a 100 ampere, 240 volt, 60 hertz, motor load with a circuit power factor of 70%. Again the circuit current through the contacts (i) and voltage across the contacts (e) are shown. The explanation of the trace is the same as Figure 1. until t_2 is reached. At t_2 the arc extinguishes and the voltage across the gap rapidly returns to the value of line voltage at point A. The rate of change in the voltage across the contact gap from t_2 to the value

of line voltage is limited only by the circuit capacitance and protector capacitance across the contact gap.

MOTOR CIRCUIT INTERRUPTION - 60 HERTZ
CURRENT AND VOLTAGE VERSUS TIME

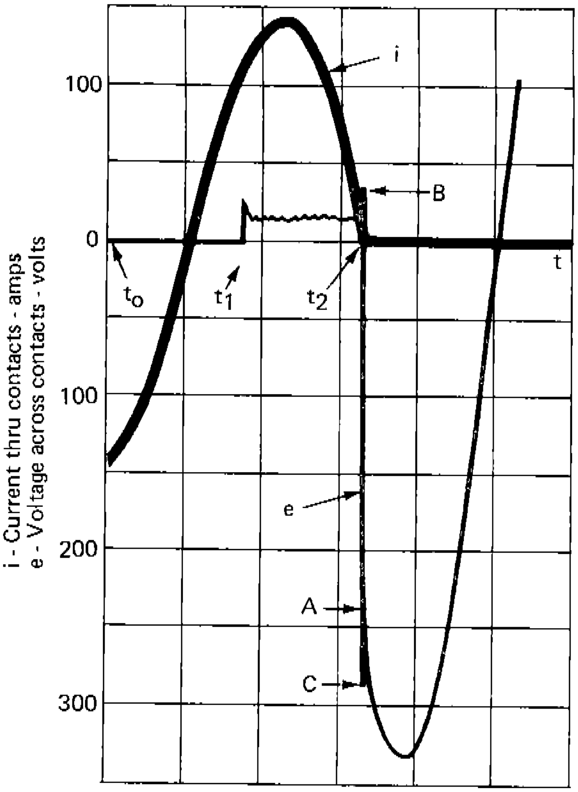

Figure 2

We also see a t_2 a positive voltage spike B caused by the collapse of the field of the inductor when the arc current is extinguished just prior to its normal zero crossover. The magnitude and width of this spike is a function of the capacitance across the gap, the inductance, and the type of inductor. A rapidly collasping field in an air core inductor will result in a high amplitude spike of narrow width, whereas in an iron core inductor a wider spike of lower amplitude will result. The width of this spike, as well as the time to traverse from t_2 to C, must be long enough to allow the recovery of sufficient dielectric strength in the contact gap for prevention of arc restrike.

The spike shown on the trace at point C is an oscillation of the returning contact gap voltage around the line voltage, A, caused by the capacitance across the gap and circuit inductance.

The value of the line voltage at point A is dependent on the circuit power factor. Figure 3, shows the impact of lower power factor on the restrike voltage at current zero for this 240 volt rms circuit. The value of the restrike voltage across the contacts for a circuit power factor of 70% would be 242 volts and is shown on the curve.

RESTRIKE VOLTAGE ACROSS CONTACTS VERSUS
CIRCUIT POWER FACTOR FOR A 240 VOLT RMS CIRCUIT

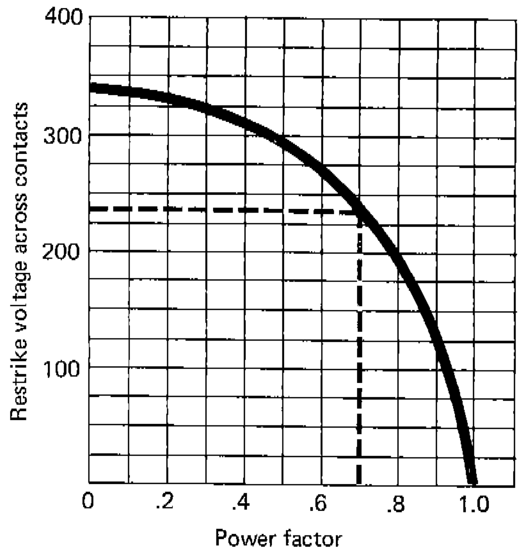

Figure 3

Now that we have a basic appreciation of the mechanism of interrupting an AC motor load by contact opening, let's look at a summary of the effect of changing circuit parameters on the interrupting capability of a protector.

EFFECT OF CIRCUIT PARAMETER CHANGES ON PROTECTOR INTERRUPTION OF AN AC MOTOR LOAD.

Line Voltage Increase

Small change in arc energy
Higher voltage at point A (Fig. 2)
— Increases chance of restrike

Circuit Current Increase

Increases arc energy
— Increases chance of restrike

Power Factor Decrease

No change in arc energy
Higher voltage at point A (Fig. 2)
— Increases chance of restrike

Change From 60 Hertz to 50 Hertz

Increases current because of lower impedance ($X_L = 2 \pi fL$)
Increases average arc duration
Increases arc energy
Lower voltage at point A (Fig. 2)
— Chance of restrike normally increased

Decrease Of Iron Losses In Inductance

No change in arc energy
Increases rate of line voltage recovery in gap
— Increases chance of restrike

COMPRESSOR MOTOR PROTECTION LIFE TESTING

Since most compressor motors are designed with power factors exceeding 70% and protectors are normally life tested in combination with the compressor, we establish rating information for compressor motor protectors by a bench test method at 70% power factor using an air core inductor shunted by a resistor. The shunt resistor is used to conservatively simulate the lowest iron losses expected in actual motors creating the most unfavorable arcing conditions. The resistor value is selected to have a loss equal to one percent of the total power consumption of that phase and is calculated by the following formulas:

$$R_s \text{ (Single Phase)} = 100 \left(\frac{1}{P.F.} - P.F.\right)\frac{E}{I}$$

$$R_s \text{ (Three Phase)} = 57.7 \left(\frac{1}{P.F.} - P.F.\right)\frac{E}{I}$$

Where: R_s = Shunt resistance
P.F. = Power factor
E = Closed circuit line voltage
I = Line current

As Underwriters Laboratories require a locked rotor cycling test in terms of days rather than number of cycles, except to require a minimum of 2000 cycles, the cycle life needed is based on the expected type of application. As an example, large hermetic protectors intended for use in compressor motors with 135 amperes locked rotor, would be expected to cycle slowly and 2000 cycles would usually be the determining factor for most applications. On the other hand, an external dome mounted protector on a household refrigerator compressor, will cycle considerably more than 2000 cycles in the 15 day minimum test period.

Published protector rating information established by this bench test method can only provide a relative guide between protector types. Protector manufacturers have always recommended that protectors must be life tested on the specific compressor, unless careful examination of similar successful compressor applications show that none of the circuit parameter or application changes will affect the life of the protector. This need for specific life testing is well appreciated by compressor and motor manufacturers. It is not widely appreciated that some production and bench test procedures that use different parameters of circuit voltage, current and power factor than those of the actual compressor, can reduce the subsequent life of the protector.

PRODUCTION LINE TESTING OF PROTECTORS

Motor and compressor manufacturers may provide a production inspection station that trips the protector under locked rotor conditions to assure reliability of the installation and to check operation of the protector. These tests when performed at rated voltage and with the rotor in place result in a normal cycling of the protector within its expected capability. Any changes from this normal test procedure must be approached with extreme caution and thoroughly evaluated as to their effect on the arc reignition and arc severity at the protector contacts. Changes that in some circumstances have caused protector arcing problems in the past include:

- Testing with the rotor removed which lowers the power factor substantially and increases the rate of line voltage recovery across the contact gap because of reduced iron losses.
- Testing with the rotor not fully inserted in the stator which will increase power factor and rate of line voltage recovery
- Simulating the rotor without taking all of the circuit parameter changes into consideration
- Increasing line voltage and current to shorten test time

SUMMARY

We have shown how changes in circuit parameters above the established ratings for a line break protector can effect the ability of the protector to break the load circuit by increasing the arc energy and increasing the chance for arc restrike. In conclusion, motor and compressor manufacturers occasionally find it expedient for production or bench tests to deviate from the published protector ratings and from the values used to establish the life of the protector/motor/compressor combination. Any such deviations should be cautiously evaluated in consulation with the protector manufacturer to assure that these abnormal tests will not have a significantly negative effect on the expected life.

REFERENCES

1) Holm, R., Electric Contacts Theory and Application, Fourth Edition, Springer-Verlag New York Inc., 1967
2) Report No. NADC-EL-L6177, Final Report Phase I Development of Standard Inductive Load Test for 115V 400 cps Switchgear, U.S. Naval Air Development Center, Johnsville, Pa., Dated 7 Sept. 1961.
3) Snowdom, A.C., Low Power A.C. Interrupting Characteristics of Cadminum Oxide-Silver Contacts, Proceeding of the International Research Symposium on Electric Contact Phenomena, University of Maine, Nov. 1961, Page 369.
4) Snowdon, A.C., Some Factors Influencing Alternating Current Interruption, Proceedings for Engineering Seminar on Electrical Contacts, Penn State University, June 1967.
5) Wilson, W.R., Life of Silver-Surfaced Contacts on Repetitive Arcing Duty, Proceedings - Part II for Engineering Seminar on Electrical Contacts, Penn State University, June 1954.
6) Veinott, C.G., Theory and Design of Small Induction Motors, McGraw-Hill Book Co., Inc. 1959.