# Impact of Circuit Breaker Pre–Strike on Transmission Line Energization Transients


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*Abstract* – **Pre–strike will occur when the dielectric withstand voltage is exceeded by the voltage between the closing contacts. The result of this phenomenon is that there is a tendency for the pre–strike to occur over the rising and peak voltage across the contacts rather than when the voltage is falling or is a minimum in magnitude. This phenomenon can impact the probability distribution of overvoltages for transmission line energizations, a possible key factor in transmission line design.**



**Keywords:** Line Energization, Switching Surges, Transmission Line Design, Pre–Strike, emtp.


## I. INTRODUCTION

The traditional method of representing a circuit breaker in emtp studies assumes that the contacts can close on any part of the cycle. In reality, there is a closing time between when the contacts start to close and when they finally make. Somewhere in between, an arc may strike across the contacts as they close.

Studies which have assumed contact making with random or pre–specified probability distributions will be different to those studies which include contact pre–strike. Just how much impact the pre–strike effect may have on the switching surge transients on line energization is discussed in this paper. A further consideration is the time span between the first pole to close and the last pole to close when the circuit breaker energizes the line.

The original concern for circuit breaker pre–strike effects was first raised by Ozay [1].

## II. PRE–STRIKE EFFECT

Figure 1 depicts the withstand voltage between the circuit breaker contacts as the vertical axis. In the open position, it is assumed in Figure 1 that the withstand voltage of the circuit breaker is equivalent to 3.0 per unit of rated voltage. The horizontal axis is time. Also depicted is the time varying voltage between the contacts as an absolute function of the alternating voltage across the circuit breaker contacts. As the contacts close, the withstand voltage reduces as the separation distance between contacts reduces. When the voltage across the contacts exceeds the reducing withstand voltage of the insulating medium between the contacts, pre–strike occurs.

As a result of the pre–strike effect, it can be deduced that for random closing, there will be a greater tendency for effective closing to occur with rising or maximum voltage across the contacts. For slow contact closing, there will

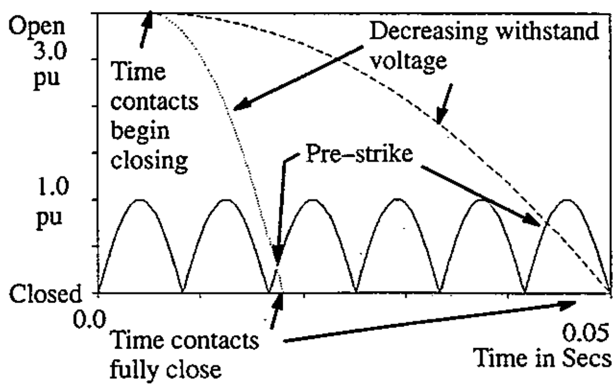



**Figure 1 Pre–strike effect in closing circuit breakers with a finite closing time**

even be a shadow effect where it will not be possible for any closing to occur over a portion of the cycle. In Figure 1, two contact closing traces can be observed. One closes in 13 msec and the other in 45 msec. The slower 45 msec contact closing trace indicates that it is not possible for the arc to be initiated on the falling side of the waveshape.

## III. MODELLING PRE–STRIKE

First of all, the open contact withstand voltage of the circuit breakers must be known. This may be expressed as a per unit value of circuit breaker peak rated voltage across the contacts for which it is designed i.e. $K.V_r$ where $K$ is the per unit open contact withstand voltage and $V_r$ is peak line–to–ground rated volts of the circuit breaker. In Figure 1 for example, $K$ would be 3.0. In reality, the dielectric strength of the insulation is not constant, but depends on the interaction of many variables. For example, the dielectric strength of the insulation medium is different for the negative and positive polarity voltages [1]. A first approximation is to maintain a consistent dielectric constant for the insulating medium between the breaker contacts.

The second important piece of information is the contact closing time $T_c$.

Another approximation is to assume the circuit breaker contacts close according to a $t^2$ law where t is time measured from the instant when the contacts commenced to close. If it is also assumed that the withstand voltage between the contacts is proportional to the distance between the contacts then;

$$K.V_r - \mathcal{V}_w = A.\, t^2 \tag{1}$$

where $t$ = time measured from the instant the contacts commence to close.

$\mathcal{V}_w$ = withstand strength in volts between the contacts which reduces as the contacts close.

$A$ = a constant.

It is known that for $t = T_c$, the contact closing time, then:

$$\mathcal{V}_w = 0.0.$$

Similarly for $t = 0$, $\mathcal{V}_w = K.\mathcal{V}_r$.

Therefore;

$$A = \frac{K\,V_r}{T_c^2} \tag{2}$$

Consequently, the withstand voltage across the closing contacts can be computed as:

$$\mathcal{V}_w = K.V_r\left(1 - \frac{t^2}{T_c^2}\right) \tag{3}$$

When the computed value of $\mathcal{V}_w$ reduces to a value less than the measured voltage across the circuit breaker contacts, then pre–strike will occur, and the circuit breaker can be effectively closed in the emtp model. The withstand voltages for the two contact closing times of 13 and 45 msec as defined by Equation (3) are plotted in Figure 1. When the voltage across the closing contacts exceeds the diminishing withstand voltage, it is assumed that an arc has been struck and that an electrical contact has been made, therefore closing the first pole.

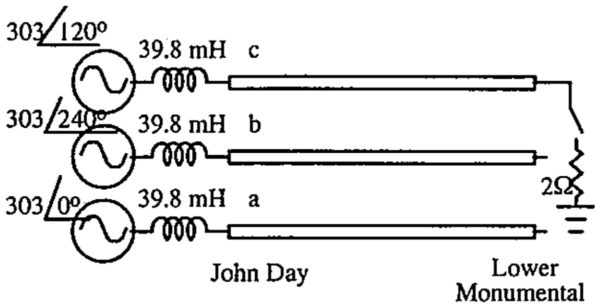
The second and third pole closures are carried out in exactly the same way except that when the first pole closes, it induces a voltage on the remaining two phases, adding or subtracting to the voltage between the contacts. This induced voltage is an important factor because it may shorten or elongate the pole closing span. The advantage of emtp simulation is that this voltage distortion across the remaining closing contacts is inherently determined and can be measured to compare against withstand voltage so that pole closure can be instigated.

With the addition of this basic model, a more realistic circuit breaker closing representation can be simulated with a resulting statistical distribution of closing which should be more representative of what might be expected on the actual system. Such a model has been graphically programmed into PSCAD™/EMTDC™ and used to examine the impact of pre–strike on line energizing.

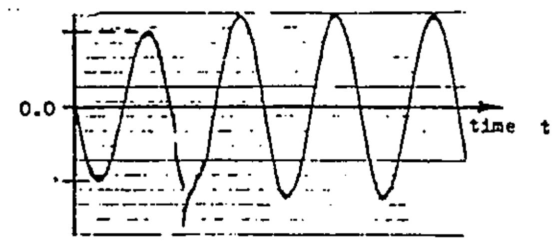
## IV. EXAMPLE TEST SYSTEM

As an example test system, the well documented transmission line field test system based on the Bonneville Power Administration's 500 kV line from John Day Station to Lower Monumental Station [2] is used. The field test is reproduced in Figure 2. Originally it was used in [2] to evaluate various EMTP line models. In Figure 2, the equivalent PSCAD™/EMTDC™ validation against the field test is presented.

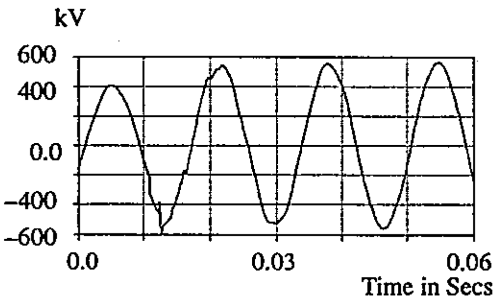
With the line model of Figure 2, a circuit breaker model is inserted at John Day and the receiving end fault removed




(a) System Configuration




(b) Field test results phase b receiving end volts




(c) Simulation results phase b receiving end volts

**Figure 2. Line model and field test results together with simulation validation**

so that all three phases remain open circuited for the pre–strike study.

## V. BREAKER CLOSING MODEL

The breaker statistical closing model assumes that one signal is received which instructs all three poles to close, but that each pole operates independently with a mean designated time to commence closing. A standard deviation defines the initiation of closing to each pole and by random number generation applied to a normal distribution, each pole can close with a different time. The span of all three poles being governed by a spread defined by the standard deviation. This is different to the EMTP models but a similar result can apply. In this case, the standard deviation of each pole's closing time was kept the same.

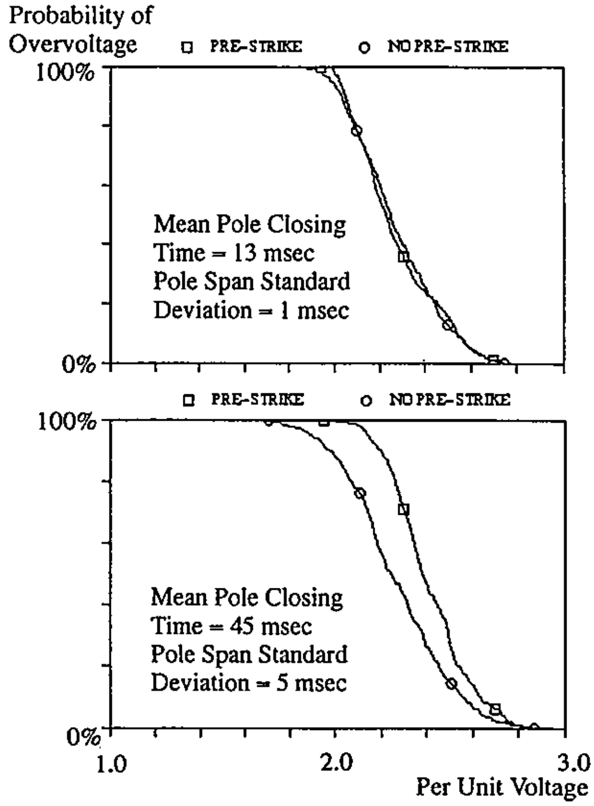



**Figure 3. Effect of Prestrike on energizing a 500 kV transmission line with and without pre–strike modelled**

The dielectric withstand strength across each set of closing contacts was computed as defined by Equation 3. Per unit open contact withstand strength *K* for the circuit breaker is selected at 3.0 per unit. To observe the effect of pre–strike, the breaker closing sequence was performed using multiple run simulation so that the probability distribution of maximum transient overvoltages on any receiving end phase could be determined.

In Figure 3, two cases are considered. One is with a breaker having a 13 msec mean closing speed and the closing span standard deviation for the three poles is 1 msec. The other is with a slower operating breaker having a 45 msec mean closing speed and a pole closing span standard deviation of 5 msec. With each case, a comparative test is shown where the pole span standard deviation is maintained but no pre–strike is in effect.

Each of the two cases were run using a multiple run feature of the digital simulation program and 500 runs for each case was selected. A random number generator available in the program enables a new selection of pole closing times for the circuit breaker to be applied for each multiple case. The breaker closing is initiated randomly over a period of one cycle (in this case over 16.6667 msecs) and each pole closes over a span defined by a normal distribution with the specified standard deviation.

## VI. CONCLUSIONS

From Figure 3 it can be observed that the probability distribution of maximum transient overvoltages is indeed effected by pre–strike but more so if the circuit breaker closes more slowly. The circuit breaker with high speed closing (ie., 13 msec mean pole closing time) does not appear to cause any significant difference whether or not re–strike occurs.

It would seem that the peak overvoltage observed is not very different for a given speed of circuit breaker but the lower speed breaker has a slightly higher peak volts. Further tests show this to be more due to the greater duration of pole span closing with the slower breaker since there is a longer period zero sequence impedance is active during energizing resulting in higher line end switching surge overvoltages.

## VII. REFERENCES

[1] N. Ozay, "Analysis of Energisation Transients of Transmission Lines," Ph.D Thesis, U.M.I.S.T., September 1971.

[2] W.S. Meyer, H.W. Dommel, "Numerical Modeling of Frequency–Dependent Transmission Line Parameters in an Electromagnetic Transient Program," *IEEE Transactions on Power Apparatus and Systems,* Vol. PAS–93, Sept/Oct 1974, No. 5, pp1401–1409.