AN EXPERIMENTAL REVISION OF TEST DUTIES IEEE C37.41 FOR DISTRIBUTION CUTOUTS AND FUSE LINKS

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Abstract.-Tests for making a comparison of performance of single-voltage-rated distribution cutouts associated with type K (fast) fuse links of different ampere rating were made under rainy and dry environment. The overcurrents applied are comprised within series 4 and 5 of IEEE Std. C37.41-1994.

A sufficient number of test were made to confirm the validity of our hypothesis of different behaviour of such devices under the indicated conditions for taking into consideration these changes proposed in future revisions of the above mentioned Standard.

INTRODUCTION

Year after year during the summer and fall seasons in the Mexican overhead radial networks are consumed a large quantity of fuse links mainly of the type K (fast) used to protect against overcurrents pole type distribution transformers. In a parallel direction the consumption of the associated cutouts and the number of damaged transformers is also important.

As it has been shown [1] when a cutout used to protect a transformer interrupts relatively small overcurrents, the voltage across its contacts will rise very quickly and can exceed the rated of buildup of dielectric strength in the medium between the contacts due to the particular characteristics of the transient recovery voltage (TRV) associated with that machine.

Practically the great majority of transformers are installed outdoors and therefore the most harmful effects can appear when under raining conditions a cutout interrupts an overcurrent, said this regardless the origin of such fault current

This is the interrupting condition that we have studied with the tests run at the High Power Laboratory of the Comisión Federal de Electricidad of México (CFE).

As an example of the quantity of fuse links operations and therefore of cutouts also, in figure 1 are showed the fuse link ratings more used to protect transformers, its total consumption during 1998 and the percentage of them operated in the rainy season in some overhead radial networks at 13.8 kV in the Central part of México.

Fuse link rating	Consumption 1998	Percentage of fuses operated during raining season
1K	12677	61.9
2K	11642	62.4
3K	12404	61.0
5K	9700	55.9
8K	7553	68.2
10K	9100	61.8

Figure 1. Consumption of type K fuse links used to protect transformers

TRANSFORMER SECONDARY FAULTS AND THE INFLUENCE OF SYSTEM ON TRV

As a cutout must be capable to interrupt a wide range of fault currents from its rated interrupting current (the less presented in our overhead networks) to the most commonly faced small primary overcurrents due to secondary faults, after current zero it is possible to have a very high rate of rise of recovery voltage (RRRV) and it can happens that the cutout does not interrupt and consequently the arcing current persists for a long period of time with long arcing, the insulation transformer can be damaged and a fault to ground may be established. Under rainfall conditions the possibility that this occurs is greater as we have found with the tests made. The TRV that appears across a circuit breaking device is a compound of the TRV contributions of the source and load sides. Each part of the complete circuit will contribute a voltage component proportional to its impedance with respect to the total fault impedance [2].

We have the following cases:

- For an ungrounded transformer, the system capacitance contributes to reduce the natural frequency.
- In a 3-phase transformer for the case of the first pole to open, the source capacitance is connected to one terminal of the transformer after the interruption of a fault and will contribute to reduce the transformer natural frequency.
- In the case of a grounded connection, after the total clearing time of the fuse-cutout, the system capacitance will be completely isolated and will not have effect on the natural frequency of the transformer.

- A 3-phase ungrounded transformer will produce a lower natural frequency when used on a grounded wye system or on an ungrounded system having substantial amount of line and cable capacitance [3].

TRV components:

Natural frequency (f) and peak factor. Both parameters are directly related to these transformer parameters:

- Impedance and capacitance
- Transformer and system ground connection
- Secondary circuits involved

With transformer impedance can be calculated the fault current magnitude and the inductance using this expression for natural frequency.

$$f = \frac{1}{2\pi\sqrt{LC}}$$

- As it was expected by theoretical predictions [3] the variation of inductance and capacitance of the testing circuit, tends to increase or decrease the severity of RRRV appearing at the cutout contacts.

TESTING CRITERIA

- For the purpose of this experimental study the range of magnitudes of primary overcurrents that were applied under dry and rain [4] conditions were comprised between 470 to 36 A. Such values are included within test series 4 and 5 of table 5 respectively of the IEEE std C37.41 applicable when testing single-voltage-rated distribution cutouts.

- Speaking about the secondary faults related to test series 5:
  - We mainly consider the 3- phase short circuit and in few cases the single-phase both at the secondary terminals of transformer.
  - In order to lengthen the useful life of the distribution transformer used, the ampere rating of the fuse links was drastically reduced.
  - Nameplate data of the distribution transformer used: 112.5 kVA, 13.2 kV, 3.5% X and Leakage inductance L= 143.8 mH.

The design tests belonging to the test series 4 and 5 of this Std are:

Parameter ↓	Test 4	Series 5
Power frequency recovery voltage	rated maximun voltage + 5%, -0%	
Transient recovery voltage (TRV)	see table 6	see foot note g
Prospective (available) current rms symmetrical	from 400 to 500 A[c]	from 2.7 to 3.3 times link rating
X/R ratio (power factor)	see table 7	from 1.3 to 0.75 (from 0.6 to 0.8)
Making angle related to voltage zero (degrees)	random timing	
Fuse link rating	min	min
Number of tests on each cutout	2	2
Duration of power Frequency recovery voltage after interruption	not less than 0.5 s dropout fuses	

The foot-notes: a, b, c, d, e and g are indicated in page 36 of the Std under revision.

For the voltage level of 13.8 kV that we have studied, the TRV parameters of table 6 for test series 4 are:

Rated maximun voltage (kV): 15.0 - 15.5

Frequency kHz + 10% - 0% : 24
Peak factor [a] + 10% - 0%[a] : 1.6

a: this foot-note is at the page 37 of the Std

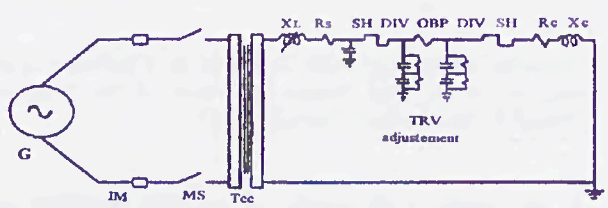
and the corresponding $^X/_R$ values given m table 7 are

Minimun $^X/_R$ b : 2.4

rated maximun voltage in kV for single-voltage-rated cutouts: 15.0 - 15.5

the foot-notes b is at the page 37 of the Std .

The testing circuit and TRV parameters are indicated in figures 2 and 3 respectively.



G	Short circuit generator	DIV	Potential divider, source side
IM	Circuit breaker	OBP	Test objet
Tcc	Short circuit transformers	DIV	Potential divider, load source
XL	Current limiting reactor	SH	Shunt, load side
Rs	Bar resistance	Rc	Load resistance
SH	Shunt, source side	Xc	Load reactance
MS	Making switch	TRV	Adjustement

Figure 2. Test circuit for series 4

Measurement Point (fig.2)	Time-to-peak tc (μs)		Frequency kHz		Peak factor	Figure ↓
1 source side	18.4		27.17		1.67	3b
2 total	18.4	104	27.17	4.80	1.63	3c

Fig. 3a. Measurement of prospective TRV

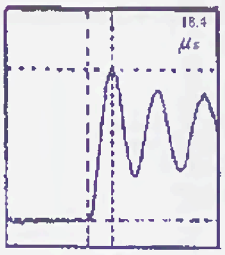


Fig. 3b

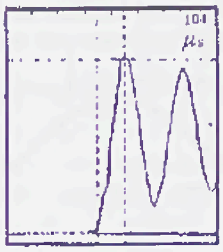
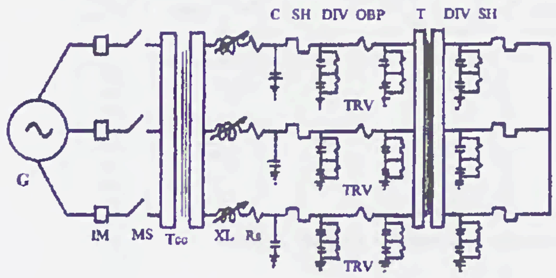


Fig. 3c

Oscillograms correspondent to prospective TRV for series 4 tests.

For the test series 5, the circuit used and the TRV parameters are shown in figures 4 and 5 respectively



G	Short circuitgenerator	SH	Shunt, source side
IM	Circuit breaker	DIV	Potential divider, source side
MS	Making swtch	OBP	Cutout under test
Tcc	Short circuit transformers	T	Distribution transformer
XL	Current limiting reactor	DIV	Potential divider, load side
Rs	Bar resistance	SH	Shunt, load side
C	Added capacitor	TRV	Adjustement

Figure 4. Test circuit for series 5

Measurement Point (fig.4)	Time-to-peak tc (μs)	Frequency kHz		Peak factor	Figure ↓
2	60	8.33	1.32	1.28	5b
2	64	7.81	1.28	1.28	5c
1	392	25.71		1.67	5d

Fig. 5a Measurement of prospective TRV

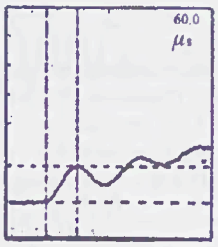


Fig.5b With the short circuit transformer grounded

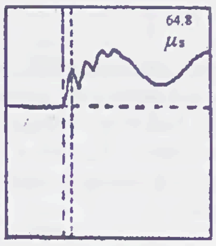


Fig. 5c With the short circuit transformer ungrounded

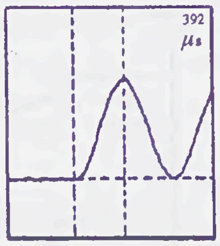


Fig. 5d Including the distribution transformer

Number of test & oscillo.	TRV data				Testing Condition dry or wet	Rated current of fuse link K	Interruption results Cutout	
	Freq. kHz	Peak factor	Time -to- peak μs	RRRV $^{V}/\mu s$			A	B
001	11	1.62	42.2	864.7	Dry	10	OK	-
002	8.7	1.6	64	223.4	"	"	-	OK
003	-	-	-	-	"	"	-	F
004	11	1.62			"	"	OK	-
005	11	1.60	55.3	497	"	"	-	OK
006	25	1.7	20	427	"	"	OK	-
007	18	1.6	27.9	214.6	"	"	-	OK
008	19.8	1.68	25.3	213	"	"	OK	-
009	-	-	-	-	"	"	-	F
010	28	1.68	0	0	"	"	OK	-
011	31	1.68	15.6	357	"	"	-	OK
012	27	1.68	18.8	377.8	"	"	OK	-
013	-	-	-	-	"	"	-	F
014	27	1.68	18.8	305.4	"	"	OK	-
015	25.4	1.68	19.7	348	"	"	-	OK
016	30.6	1.68	30.6	308	"	"	OK	-
017	25	1.68	20	375	"	"	-	OK
018	25.7	1.68	19.4	393	"	"	OK	-
019	-	-	-	-	Wet	"	-	F
020	-	-	-	-	"	"	F	-
021	-	-	-	-	"	"	-	F
022	27	1.68	17.6	346	"	"	OK	-
023	25.2	1.68	17.8	317	"	"	-	OK
024	-	-	-	-	"	"	-	F
025	28	1.68	17.4	360.1	"	"	OK	-
026	-	-	-	-	"	"	-	F
027	29	1.68	17.1	417	"	"	OK	-
028	20	1.68	25.3	273	"	"	-	OK
029	-	-	-	-	Wet	"	F	-
030	-	-	-	-	"	"	-	F
031	-	-	-	-	"	"	F	-
032	-	-	-	-	Dry	6	-	F
033	21.7	1.68	23.8	302.4	"	6	OK	-
034	28	1.68	17.2	323.8	"	6	-	OK
035	28	1.68	17.6	389.6	"	6	OK	-
036	25	1.68	19.5	452	"	6	-	OK
037	26	1.68	18.8	400.6	"	6	OK	-
038	26	1.68	18.6	347.6	Wet	6	-	OK
039	27.4	1.68	18.2	435.4	"	6	OK	-
040	-	-	-	-	"	6	-	F
041	29	1.68	16.7	479.3	"	6	OK	-
042	27	1.68	17.3	354.5	"	6	-	OK
043	26.4	1.68	18.9	349	"	6	OK	-

Fig.6 Summary of laboratory interrupting test data corresponding to test series 4

RESULTS

In figures 6 are summarized the results attained for test series 4 for dry and wet testing conditions. From tests 001 to 031 the laboratory data were: voltage= 15.3 kV, test current = 427 A, X_L surce =30 Ω $^X/_R$ ratio = 2.6 and from tests 032 to 043 these were the changes: voltage = 15.6 Kv, test current = 416 A, $^X/_R$ ratio = 2.9

Remarks:

- For test numbers 001 to 040, the fuseholders were changed after four operations

The fuseholders used to test 6K links were previously used for test numbers 41, 42 and 43

- In this figure it is easy to see the effect of the ampere rating of fuse links the number of failures is reduced in both testing environments.

In figures 7 and 8 are shown oscillograms of a successful interruption under dry conditions and in figures 9 is shown an oscillogram of a faulted test made under wet environment. In both tests were used 10K fuse links.

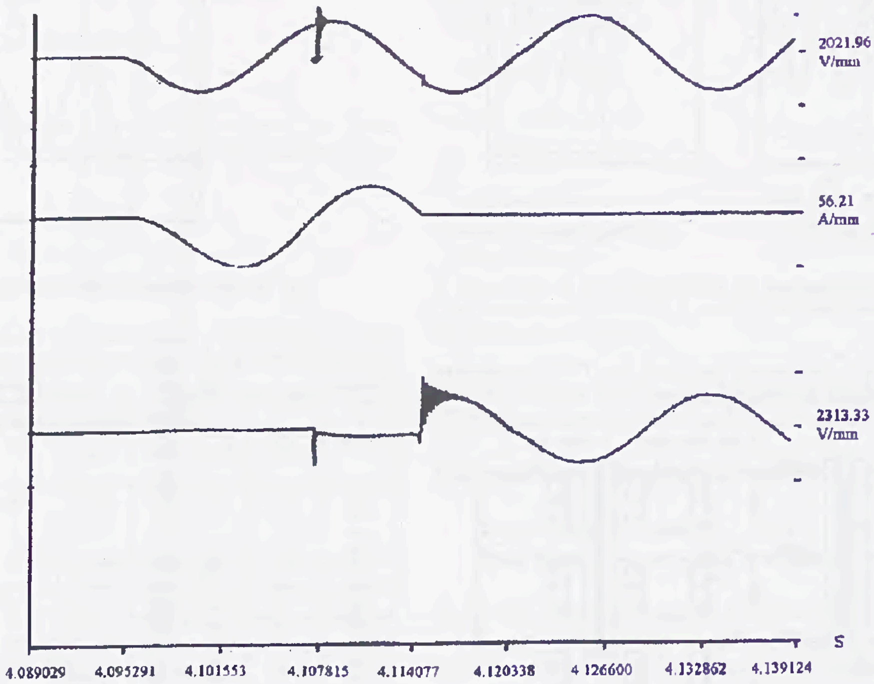


Figure 7. Satisfactory interruption of 427 A. Cutout A with 10K fuse link. Dry test

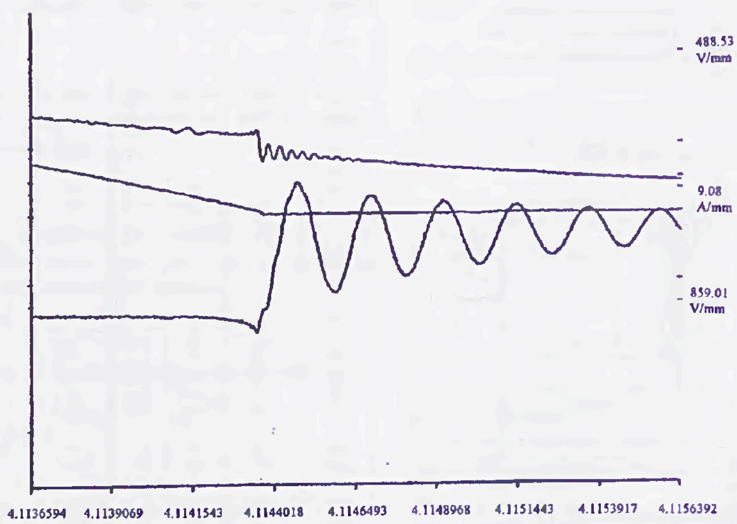


Figure 8. TRV across the cutout contacts after the successful interruption shown in fig. 7

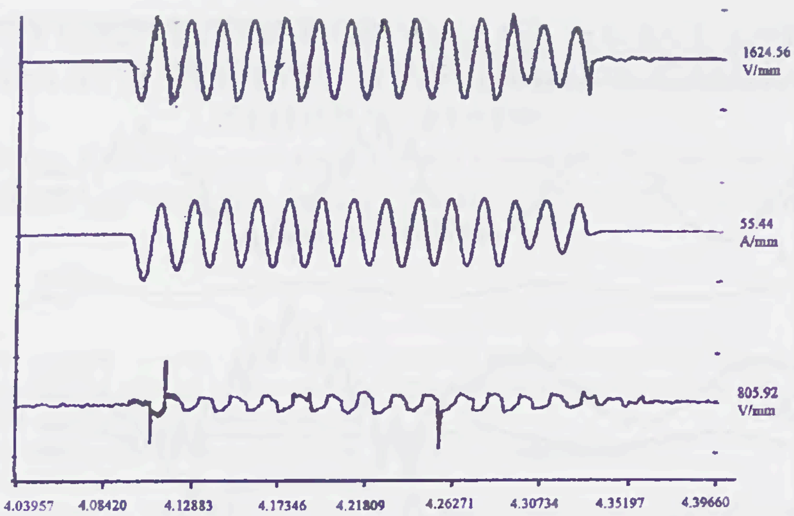


Fig. 9. Failure of the cutout A for interrupting 427, with a 10K fuse link. Wet test. External flashover of the fuseholder

In figure 10 are summarized the results obtained for test series 5 made under dry and wet environment.

In all cases the voltage applied was: 15.3 kV phase-to-phase.

Number of test & oscillo	Laboratory data				TRV data				Testing condition dry or wet	Rated current of fuse link K	Interrption results		
											Cutout		
	Test current A	X_L source Ω	X/R ratio	C add nF	Frequency kHz	Peak factor	Time-to-peak μs	RRRV V/μs			A	B	B
001	75	49.9	7.4	-	-	-	-	-	Dry	3K	F	F	F
002	"	"		-	-	-	-	-	-"	3K	F	F	F
003	"	"	"	-	-	-	-	-	"	3K	F	F	F
004	"	"	"	-	-	-	-	-	"	6K	F	F	F
005	"	"	"	-	-	-	-	-	"	6K	F	F	F
006	"	"	"	-	-	-	-	-	"	2K	F	F	F
007	"	"	"	-	-	-	-	-	"	2K	F	F	F
008	"	"	"	500	446		1120	10	"	2K	OK	OK	OK
009	"	"	"	500	477		1049	15.4	"	2K	OK	OK	OK
010	"	"	"	125	-	-	-	-	"	2K	F	OK	F
011	"	"	"	125	-	-	-	-	"	2K	F	F	F
012	"	"	"	125	-	-	-	-	"	3K	F	F	F
013	"	"	"	125	-	-	-	-	"	3K	F	F	F
014	"	"	"	125	-	-	-	-	"	2K	F	OK	F
015	"	"	"	125	-	-	-	-	"	2K	F	F	F
016	"	"	"	125	-	-	-	-	"	6K	F	F	F
017	40	122.8	5.4	250	563		889	23	"	6K	OK	OK	OK
018	40	122.8	"	250	-	-	-	-	"	6K	F	F	F
019	40	122.8	"	250	-	-	-	-	"	6K	F	OK	F
020	40	122.8	"	250	821		609	12.7	"	6K	OK	OK	OK
021	36	-	"	250	347		1440	19.9	"	6K	OK	OK	OK
022	36	-	"	250	400		1250	9.7	Wet	6K	OK	OK	OK
023	"	-	"	250	874		572	21.2	"	6K	OK	OK	OK
024	"	-	"	125	-	-	-	-	"	8K	F	F	F
025	"	-	"	125	767	-	770	19.8	"	8K	F	OK	F
026	"	122.8	"	125	-	-	-	-	Dry	8K	F	F	OK
027	"	"	"	125	-	-	-	-	"	8K	F	F	F
028	"	"	"	125	-	-	-	-	"	8K	F	F	F
029	"	"	"	"	645		776	16.2	Wet	8K	OK	OK	OK
030	"	"	"	"	483		1036	15.6	"	8K	OK	OK	OK
031	"	"	"	"	-	-	-	-	"	8K	F	F	OK
032	"	"	"	"	-	-	-	-	Dry	8K	F	F	F
033	"	"	"	"	-	-	-	-	"	8K	F	F	OK
034	"	"	"	"	-	-	-	-	"	6K	OK	OK	F
035	"	"	"	"	-	-	-	-	"	6K	OK	F	F
036	"	"	"	"	-	-	-	-	"	6K	F	F	1Ø
037	"	"	"	"	-	-	-	-	"	3K	OK	F	1Ø
038	"	"	"	"	-	-	-	-	"	3K	OK	OK	1Ø
039	"	"	"	"	-	-	-	-	"	3K	F	F	1Ø
040	"	"	"	"	-	-	-	-	Wet	6K	OK	OK	1Ø
041	"	"	"	"	542		922	18.1	"	6K	OK	OK	1Ø
042	"	"	"	"	327		1529	8.2	"	8K	OK	OK	1Ø
043	"	"	"	"	558		896	19.8	"	8K	OK	OK	1Ø

Figure 10 Summary of laboratory interrupting test data corresponding to test series 5.

In figure 11 are shown the TRV characterictics of a successful 3-phase test made under wet enviroment.In this case the lumped capacitance was of 125 nF por-phase

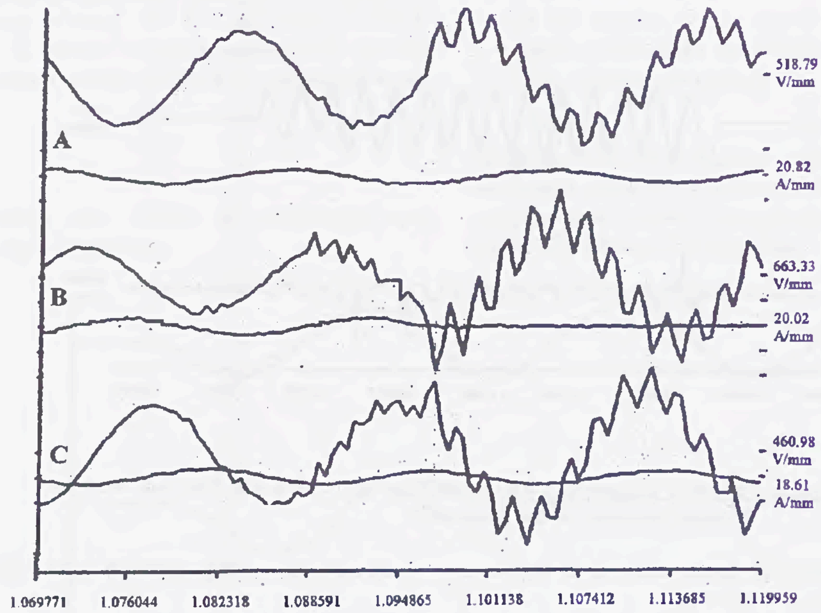


Figure 11. TRV characteristics on phase B, 3-phase test 029, made under wet environment with 8K fuse links

Remarks:

- When was not included a lumped capacitance in all cases we had a spectacular failure.
- With lumped capacitances of 250 nF and greater, the number of failures was drastically reduced.
- For the 3-phase faults when using 8K links and lumped capacitances of 125 nF per phase the results found were aleatory in both testing conditions.
- In the case of single-phase tests the number of satisfactory results of 3K, 6K, and 8K links was improved.

CONCLUSIONS.

After having revised carefully the results obtained for both series studied with approximately 180 tests, our recommendations are these:

- When a fault current of magnitude considered between the limits given by the test series 4 and 5, is applied under rain, the interruption of the fuse cutout is much more difficult and therefore is necessary to consider this testing condition.
- As it is well known that a more severe interruption can be presented when is applied a symmetrical current because the TRV occurs near or at the maximun of power frequency voltage we propose to test using a making angle between 85 to 105 degrees for test series 4. Obviously this conditions may be more critical for low and intermediate ampere rating of fuse links.
- Therefore we recommend to include an intermediate ampere rating besides to the minimun and maximun now indicated.

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