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EFFICIENCY THRESHOLD CRITERION IN COUPLING FORKED MOVING CONTACTS CIRCUIT BREAKERS AND CURRENT LIMITING REACTORS

[1]Akpeh V.A, [2]Ezechukwu O.A
[1] Transmission Company of Nigeria (TCN)
[2]Department of Electrical Engineering, Nnamdi Azikiwe University, Awka

ABSTRACT

This paper establishes the efficiency threshold criterion for the use of forked moving contacts on power circuit breakers (CBs) to enhance parallel operation of circuit breaker/current limiting reactor that approximates series short-circuit current limiting reactor connection with no constant power losses [1, 2]. It provides adequate guide for selecting appropriate Current Limiting Reactor (CLR) inductance (reactance) for an efficient power circuit breaker operating mechanism energy requirement and cost.

KEYWORDS: Circuit breaker, Criterion, Current Limiting Reactor, Efficiency, Forked moving contact, Inductance, Operating mechanism energy, Parallel operation, Reactance, Straight moving contact, Threshold.

INTRODUCTION

The use of forked moving contacts in circuit breakers gives CB/CLR connection arrangement that approximates a series short-circuit CLR connection that removes constant power losses in power systems [3]. In forked moving contact implementation meant for parallel operation of CB/CLR [4, 5, 6], there is an increased overall length of contact and reduced cross-sectional area. The meaning of this is that as the short-circuit current is reduced downwards; there is an initial increase in the mass of the forked moving contact up to a certain point after which the mass starts decreasing.

The short-circuit level below which the mass of the forked moving contact of a CB begins to reduce when compared with the mass of a straight moving contact of another CB on the same system without any short-circuit current limiting reactor, is very important in determining the operating mechanism energy requirement reduction and cost reduction for forked moving contact power circuit breakers. This point at which the short-circuit current must be reduced to; below which a reduced mass of forked moving contact when compared with that for the straight moving contact is obtained, is the efficiency threshold.

EFFECTS OF RATED SHORT-CIRCUIT BREAKING CURRENTS ON THE OPERATING MECHANISM ENERGY REQUIREMENTS OF A POWER CIRCUIT BREAKER

RATED SHORT-CIRCUIT BREAKING CURRENTS AND THE BLAST PRESSURE

The rated short-circuit breaking current i, exercises its influence on the required operating mechanism energy mainly through the blast pressure ΔP which is necessary to warrant reliable arc-quenching under short-line fault conditions. Experimental results show the relationship between the required blast pressure ΔP and the current slope $\frac{di}{dt}$ as:

$$\Delta P \propto \left[\frac{di}{dt}\right]^a \qquad (1)$$

Where:

The constant 'a' assumes a value between 1.1 and 1.42, depending on the filling pressure P_o in the circuit breaker [7].

However, as already confirmed by many authors, blast pressure ΔP, can be reduced by increasing the number of breaks N. With the well known relationship between current slope $\frac{di}{dt}$ and the rate of rise of re-striking voltage (RRRV) $\frac{dv}{dt}$

$$\frac{dv}{dt} \cdot \left[\frac{di}{dt}\right]^n = \text{constant} \qquad (2)$$

With large varying values between 1 and 7 as is always the case, specified for n, the effect of N on ΔP can be obtained as follows:

$$\Delta P \propto i^a . N^{-a/n} \qquad (3)$$

If a value of 1.4 is substituted for ‘a’ and a value of 5 for ‘n’ in equation (3), the following results:

$$\Delta P \propto i^{1.4}.\ N^{-0.28} \qquad (4)$$

The response curve arising from equation (4) is as shown in figure 1.

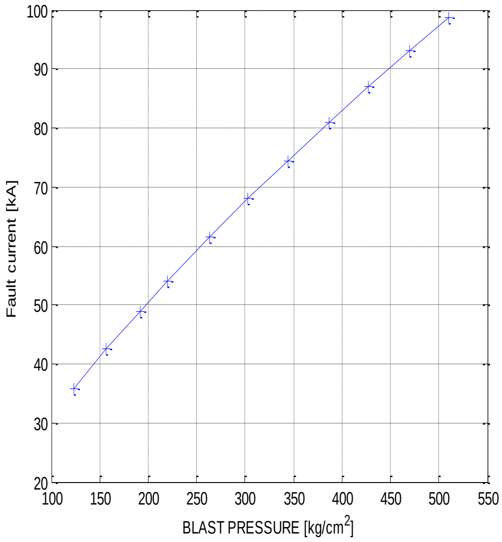

Figure 1: Response curve of blast pressure against fault current

RATED SHORT-CIRCUIT BREAKING CURRENTS AND THE MOVING CONTACT AREA

The rated short circuit breaking current also has effect in the required blast volume, or if the contact stroke is not modified, the piston area, A, will be influenced because the nozzle cross-section has to be adapted to the arc cross-section A_A. As a first approximation, the following relationship can be assumed:

$$A \propto A_A \propto \frac{i}{\sqrt{P}} \qquad (5)$$

As the pressure $P = P_0 + \Delta P$ depends again on the current, the dependence of the nozzle cross-section and the Piston area on current is less than one would expect. For large blast pressure, ΔP is much greater than P_0, i.e.

$$\Delta P >> P_0$$

And thus,

$$P \approx \Delta P$$

Where

P = pressure
A = piston area
ΔP = blast pressure
P_0 = filling pressure
A_A = arc cross-section

Substituting equation (4) in (5) gives

$$A \propto \frac{i}{\sqrt{(i^{1.4}.N^{-0.28})}}$$

This implies

$$A \propto \frac{i}{i^{0.7}.N^{-0.14}}$$

i.e.

$$A \propto i \text{ x } i^{-0.7} \text{ x } N^{0.14}$$

Or

$$A \propto i^{0.3} \text{ x } N^{0.14} \qquad (6)$$

The response curve arising from equation (6) is shown in figure 2.

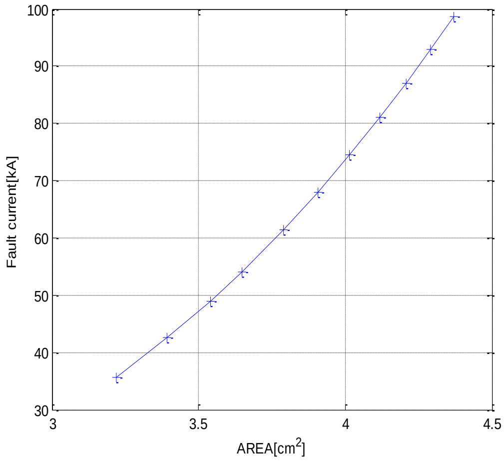

Figure 2: Response curve of the moving contact area against the fault current

THE BLAST PRESSURE AND THE COMPRESSION WORK

The relationship between blast pressure ΔP and compression work, W_{comp}, is not simple since one part of the blast pressure is produced by the arc through heating up. Assuming a linear relationship as a rough approximation [7], ΔP relates with the compression work, W_{COMP} thus:

$$W_{COMP} \propto N.A.\,\Delta P \qquad (7)$$

But

$$\sqrt{P} \propto \frac{i}{A}$$

And

$$P = P_0 + \Delta P \qquad (8)$$

But for large blast pressure: $\Delta P \gg P_0$ and so $P \approx \Delta P$.

From equation (6),

$$A \propto i^{0.3}.N^{0.14}$$

Substituting equations (4) and (6) in equation (7) gives

$$W_{COMP} \propto N.i^{0.3}.N^{0.14}.i^{1.4}.N^{-0.28}$$

OR

$$W_{COMP} \propto N^{0.86}.i^{1.7} \qquad (9)$$

The response curve of equation (9) is shown in figure 3.

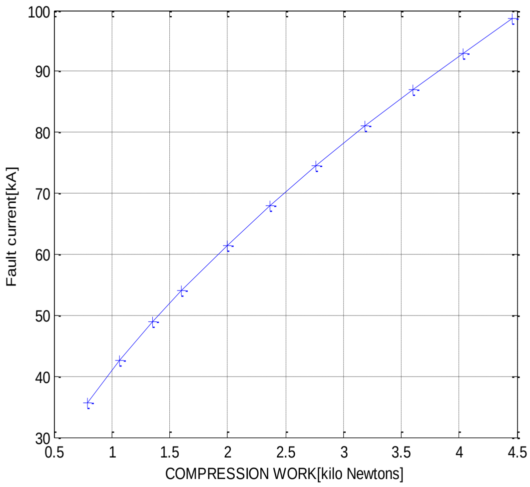

Figure 3: Response curve of compression work against fault current

THE MOVING CONTACT MASS

The mass of the copper moving contact, M, is the product of its volume, V, and the density, d. i.e.

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M = d x V
But
V = h x A
Where
h = the height (i.e. the length) of the moving contact and
A = the cross sectional area of the moving contact.
But from equation (6), $A \propto i^{0.3} \times N^{0.14}$ Such that:

$$M = d \times h \times i^{0.3} \times N^{0.14} \quad (10)$$

The effect of the increased overall length (height) of the forked moving contact rod on its mass [2], is shown in the response curves given in figure 4, while some selected fault levels and the corresponding effect of the increased overall length (height) of the forked moving contact rod on its mass is given in tables 1.

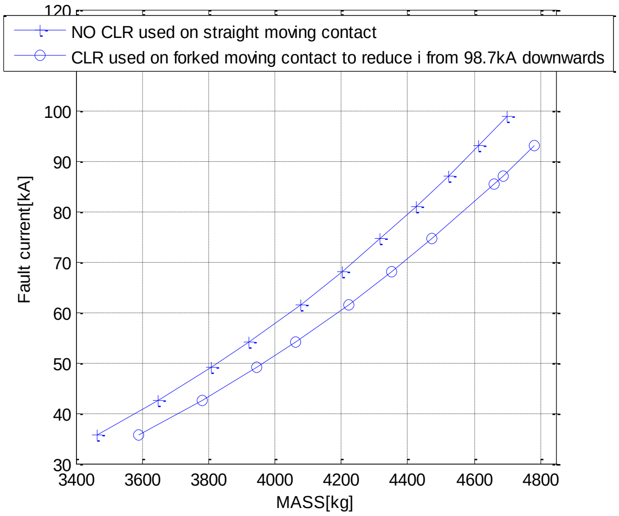

Figure 4: Response curves of the overall mass of the straight and the forked moving contact against the fault current.

Table 1a: Fault current and the corresponding mass of moving contact rod (straight rod of 120cm length)

FAULT CURRENT (kA)	MASS OF MOVING CONTACT ROD (kg)
35.7000	3.4629
42.5000	3.6488
49.0000	3.8080
54.0000	3.9206
61.5000	4.0766
68.0000	4.2013
74.5000	4.3180
81.0000	4.4277
87.0000	4.5237
93.0000	4.6151
98.7000	4.6982

Table 1b: Fault current and the corresponding mass of moving contact rod (forked rod of 124.33cm overall length)

FAULT CURRENT (kA)	MASS OF MOVING CONTACT ROD (kg)
35.7000	3.5878
42.5000	3.7805
49.0000	3.9454
54.0000	4.0621
61.5000	4.2237

68.0000	4.3529
74.5000	4.4738
85.3000	4.6592
85.4000	4.6609
87.0000	4.6869
93.0000	4.7816

CURRENT REDUCTION AND THE FORKED MOVING CONTACT MASS

When the moving contact is forked, the overall length (height) is slightly increased. From the expression: Mass = volume (i.e. area x height) x density, it appears there could be increased mass and as such increased operating mechanism energy but as shown in equations (6), (7) and (9), reducing the current reduces the cross-sectional area of the moving contact rod and the compression work, 'W_{COMP}'. That is, the mass of the moving contact rod is reduced even though the height is slightly increased as can be seen in the response curve of the moving contact area against the fault current, for the values of 'I' between 35.7kA and 98.7kA and for number of breaks, 'N' = 2, shown in figure 2.

This is clearly seen in the response curve of fault current reduction against the overall mass of the forked moving contact rod of the CB (overall length = 124.33cm) [2], compared with the mass of the required (straight) moving contact rod (length = 120cm) when no CLR is used, shown in figure 4. However, it should be noted from figure 4 that the fault current must be reduced below a certain limit (the efficiency threshold) before the mass of the rod begins to decrease else, the mass is higher.

DISCUSIONS

As shown with the aid of equation (10), in table 2, which resulted to table 3, it can for instance be seen that, limiting the fault current from 98.7kA to 87.8kA shows an increase in the mass of the rod (i.e. above 4.6982kg value gotten at 98.7kA for a straight moving contact rod), but reducing 98.7kA below 87.8kA yields the desired result. The efficiency threshold for this case is therefore 87.7kA.

Table 2a: Fault current and corresponding cross-sectional area, volume, and mass of the straight moving contact rod of length = 120cm.

FAULT CURRENT (kA)	CROSSECTIONAL AREA OF MOVING CONTACT ROD (cm^2)	VOLUME OF MOVING CONTACT ROD (cm^3)	MASS OF MOVING CONTACT ROD (kg)
98.7	4.3696	524.3492	4.6982
93.0000	4.2923	515.0748	4.6151
87.0000	4.2073	504.8719	4.5237
85.3000	4.1824	501.8919	4.4970
68.0000	3.9075	468.8977	4.2013
61.5000	3.7915	454.9755	4.0766
54.0000	3.6464	437.5660	3.9206
49.0000	3.5416	424.9954	3.8080
42.5000	3.3936	407.2322	3.6488
35.7000	3.2207	386.4790	3.4629

Table 2b: Fault current and corresponding cross-sectional area, volume, and mass of the forked moving contact rod of overall length = 124.33cm.

FAULT CURRENT (kA)	CROSSECTIONAL AREA OF MOVING CONTACT ROD (cm^2)	VOLUME OF MOVING CONTACT ROD (cm^3)	MASS OF MOVING CONTACT ROD (kg)
98.7000	4.3696	543.2694	4.8677
93.0000	4.2923	533.6604	4.7816
87.7000	4.2174	524.3485	4.6982
87.6000	4.2159	524.1690	4.6966
87.0000	4.2073	523.0894	4.6869
68.0000	3.9075	485.8171	4.3529
61.5000	3.7915	471.3925	4.2237
54.0000	3.6464	453.3548	4.0621

49.0000	3.5416	440.3307	3.9454
42.5000	3.3936	421.9265	3.7805
35.7000	3.2207	400.4245	3.5878

Table 3a: The effect of the use of CLR on the overall mass of the forked CB moving contact rod.

Fault current (kA) with no CLR	Mass of straight moving contact rod (kg) with no CLR used	98.7kA limited downwards with CLR	Corresponding mass of forked moving contact rod (kg) with CLR used
98.7000	4.6982		
		93.0000	4.7816
		87.7000	**4.6982**
		87.6000	4.6966
		87.0000	4.6869
		68.0000	3.2910
		61.5000	3.1933
		54.0000	3.0711
		49.0000	2.9829
		42.5000	2.8582
		35.7000	2.7126

Table 3b: The effect of the use of CLR on the overall mass of the forked CB moving contact rod.

Fault current (kA) with no CLR	Mass of straight moving contact rod (kg) with no CLR used	93kA limited downwards with CLR	Corresponding mass of forked moving contact rod (kg) with CLR used
93.0000	4.6151		
		88.0000	4.7030
		85.0000	4.6543
		82.6400	**4.6151**
		68.0000	4.3529
		61.5000	4.2237
		54.0000	4.0621
		49.0000	3.9454
		42.5000	3.7805

Table 3c: The effect of the use of CLR on the overall mass of the forked CB moving contact rod.

Fault current (kA) with no CLR	Mass of straight moving contact rod (kg) with no CLR used	87kA limited downwards with CLR	Corresponding mass of forked moving contact rod (kg) with CLR used
87.0000	4.5237		
		85.0000	4.6543
		77.3050	**4.5237**
		68.0000	4.3529
		61.5000	4.2237
		54.0000	4.0621
		49.0000	3.9454

Table 3d: The effect of the use of CLR on the overall mass of the forked CB moving contact rod.

Fault current (kA) with no CLR	Mass of straight moving contact rod (kg) with no CLR used	68kA limited downwards with CLR	Corresponding mass of forked moving contact rod (kg) with CLR used
68.0000	4.2013		
		64.0000	4.2745
		60.4200	**4.2013**
		54.0000	4.0621
		49.0000	3.9454
		42.5000	3.7805
		35.7000	3.5878

Table 3e: The effect of the use of CLR on the overall mass of the forked CB moving contact rod.

Fault current (kA) with no CLR	Mass of straight moving contact rod (kg) with no CLR used	54kA limited downwards with CLR	Corresponding mass of forked moving contact rod (kg) with CLR used
54.0000	3.9206		
		50.0000	3.9693
		47.9810	**3.9206**
		45.0000	3.8458
		40.0000	3.7123
		38.0000	3.6556
		35.7000	3.5878

In all the cases examined above, it is observed that as short-circuit current limiting reactor is used on the forked moving contact circuit breaker to reduce the short-circuit level, the mass of the forked moving contact when compared to that for the straight moving contact used in the same system with no current limiting reactor, increases to a point and then starts decreasing as shown in figure 4 and tables 3a to 3e. The current below which the mass of the forked moving contact begins to reduce is the efficiency threshold for the forked moving contact CB.

The Current limiting reactor is not arbitrarily chosen for any particular system under study. There is the efficiency limit consideration. The efficiency limit of the current limiting reactor is the effective value of the impedance (reactance) required for the system under study [8]. The efficiency threshold is therefore very necessary in determining the impedance value of the Current limiting reactor needed to limit the anticipated short-circuit level in a given power system for an efficient power circuit breaker operating mechanism energy requirement and cost.

CONCLUSIONS

This paper has presented an efficiency threshold criterion which is very necessary in determining the optimum operating mechanism energy requirement and cost for a forked moving contact power circuit breaker. The implication of this is that the series short-circuit current limiting reactors to be used in conjunction with the forked moving contact power circuit breakers are not arbitrarily chosen without due consideration to this efficiency threshold criterion to ensure minimal power circuit breaker operating mechanism energy requirement as well as cost minimization.

REFERENCES

[1] Akpeh, V.A., Madueme, T.C. and Ezechukwu, O.A. (2015). A new approach to Implementing Fault Current Limiting Reactors (CLRs) on Feeders with Negligible Constant Power losses. India: International Journal of Modern Engineering Research. 5, (11), 37-46.
[2] Akpeh, V.A. and Echedom, V.C. (2017). Forked Moving Contacts in Power Circuit Breakers: Solution to Constant Power Losses Incurred in the Use of Series Shot-circuit Current Limiting Reactors on Feeders. Global Journal of Advanced Engineering Technologies and Science 4, (4) 1-15.
[3] Akpeh V.A., Madueme T.C., Ezechukwu O.A., Ogboh V.C., Echedom V.C. (2015). A Methodology for Implementing Fault Current Limiting Reactors (CLRs) on Feeders with Minimal Constant Power Losses. Global Journal of Engineering, Design & Technology, 4, (5), 1-7.
[4] Brandt, A., Hartung, K.H., Bockholt, R. and Schmidt, V. (2010). IS – limiter: Limitation of Shortcircuit Currents for maximum economic benefits. ABB AG - 40472 Ratingen (Germany), pp. 1-4.
[5] Akpeh, V.A. and Omini, G.U. (2017). Improved I_s – Limiter Technique for Implementing Fault Current Limiting Reactors on Feeders at no Constant Power Losses. India: International Journal of Engineering Sciences & Research Technology 6, (4), 273- 276.
[6] Hartung, K.H. (2002). Is-Limiter, the Solution for High Short-Circuit Current Applications. ABB Calor Emag. 12-18.
[7] Bachofen, F., Steinegger, P. and Glauser, R. (1982). A Novel Solution for High Speed SF_6 Puffer Type Power Circuit Breakers of High Rated Capability with Low Operating Mechanism Energy. Paris: International Conference on Large High Voltage Electric Systems. Cigre WG 13-07. 1-8.
[8] Geng, Z. X., Lin, X., Xu, J.Y. and Tian, C. (2008). Effects of Series Reactor on Short-circuit Current and Transient Recovery Voltage. Chongqing: International Conference on High Voltage Engineering and Application. 2008 Report, 524-526.