UDC [621.316.573:621.31-78] : [621.314.5:621.382.3]

APPLICATION OF EARTH LEAKAGE CIRCUIT BREAKERS TO INVERTER CIRCUITS

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1. FOREWORD

More than 20 years have passed since production of earth-leakage circuit breakers (ELCB) was started in Japan. During this time, the popularity of the ELCB has spread rapidly and their range of applications has become very wide by legal restrictions on ground fault protection and the rise of safety consciousness to electrical shock accidents.

On the other hand, changes in the economic environment have given birth to new needs in the industrial world and new products corresponding to these needs have been steadily developed. Popularization to inverter circuits that perform motor speed control can be given as the largest change from the standpoint of the ELCB application environment. Since the second oil shock of 1980, the inverter has rapidly become popular due to the need to save energy and it is currently used in a wider range of fields. However, application of the ELCB to inverters created a new problem. This is the need to consider nuisance tripping by high frequency leakage current.

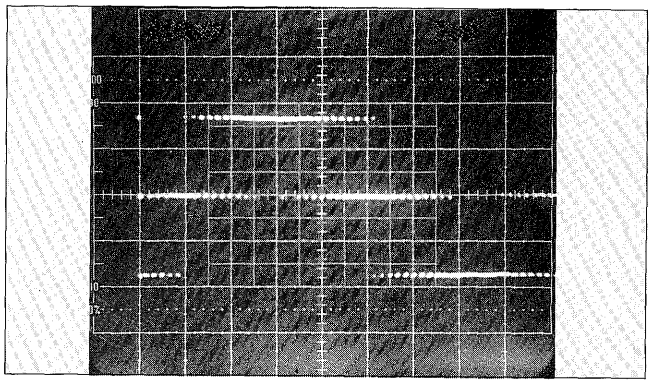
Regarding this problem, Fuji Electric conducted application studies based on the technological cooperation of the concerned parties from the beginning of popularity of the inverter and improved the characteristics of the Fuji ELCB(ELB) from July 1983. At the same time, correspondence was performed by preparing selection guide table of ELCB sensitivity when applied to inverter circuits. The high frequency leakage current generation mechanism by inverter, contents of ELCB characteristics improvements, and ELCB application methods are described.

2. INVERTER AND HIGH FREQUENCY LEAKAGE CURRENT

2.1 High frequency leakage current generation mechanism

An inverter converts commercial frequency power to direct current and outputs a voltage with the waveform shown in *Fig. 1* by switching the output side transistor at

Fig. 1 Inverter output voltage waveform



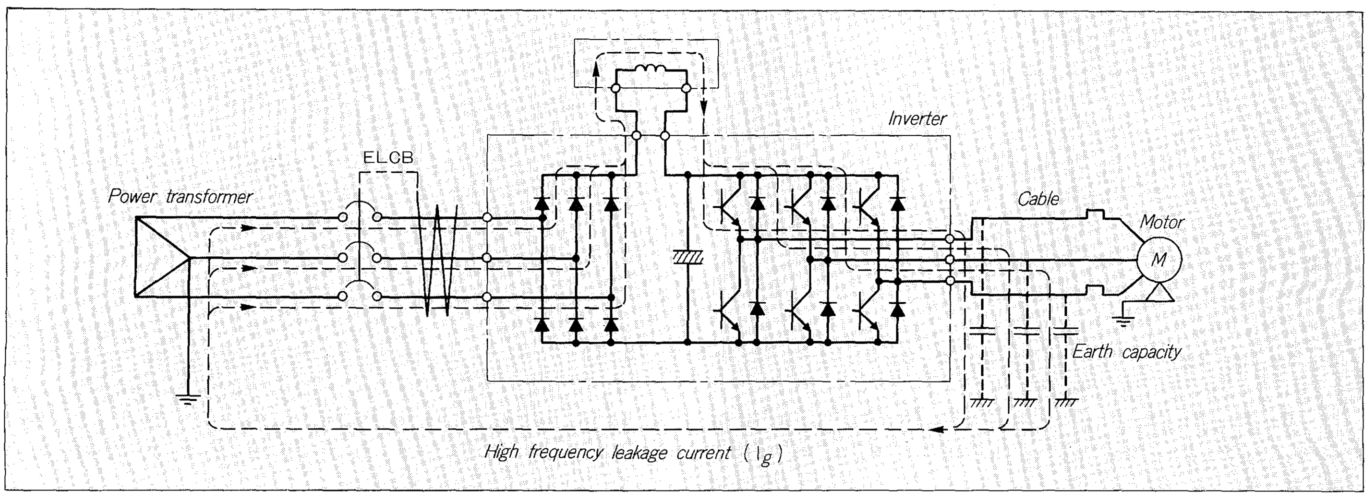


Fig. 2 High frequency leakage current generation and current path

Fig. 3 Example of high frequency current waveform

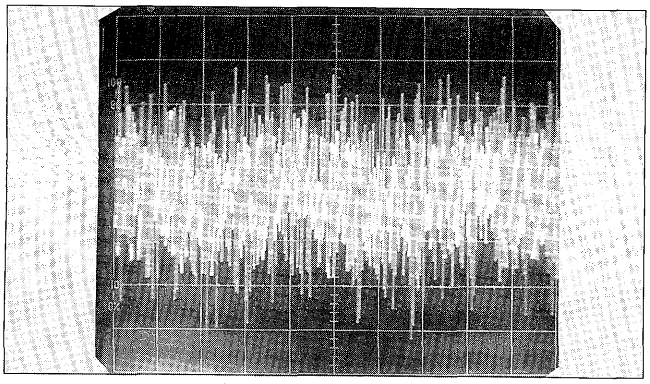


Fig. 4 System model connecting ELCB and inverter

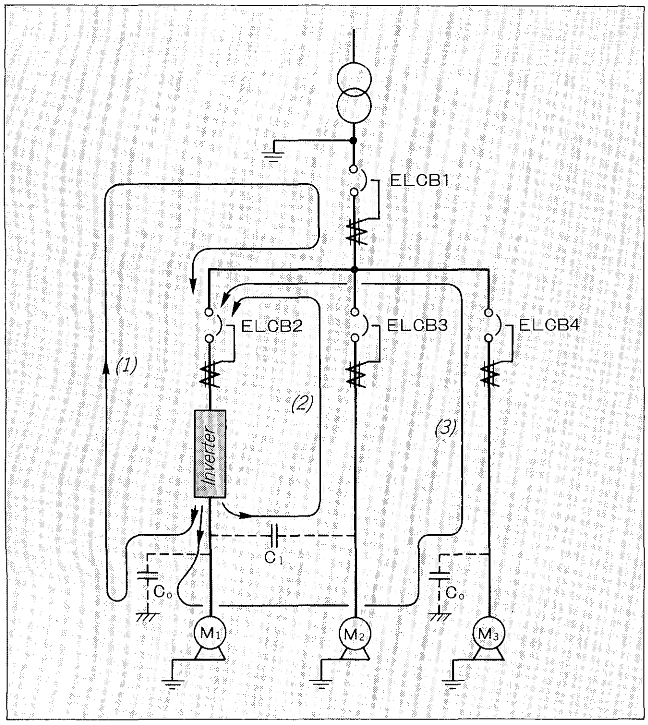
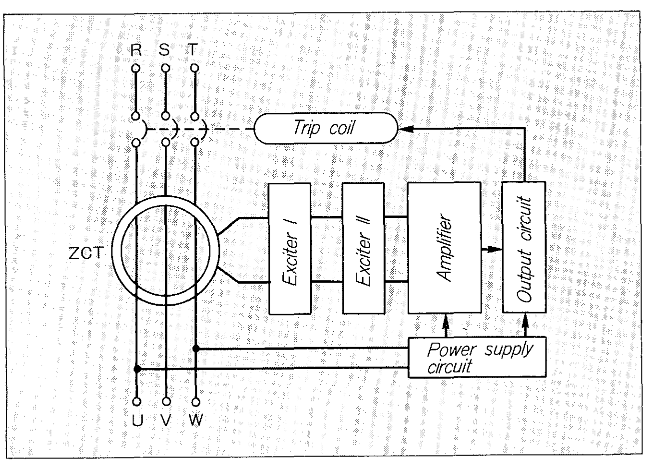


Fig. 5 ELCB internal circuit block diagram



high speed. Therefore, a high frequency voltage is generated at the inverter output. This high frequency voltage generates a high frequency leakage current as shown in *Fig. 3* through the earth capacity of the inverter load side cable and the motor. The high frequency current returns to the power line from the earthing line conductor of the transformer through the earth and returns to the inverter through the ELCB. Therefore, depending on the size of the high frequency leakage current, it causes the ELCB to operate. When the frequency of this high frequency leakage current is measured at an actual circuit, a frequency up to several hundred kHz, centered about 3 to 10kHz (carrier frequency).

2.2 High frequency leakage current path in electric power system

A model of a system connecting an ELCB and inverter is shown in *Fig. 4.* The high frequency leakage current is not only circulated through the earth capacity between the inverter load side cable and the earth, but may also effect other circuits, depending on the cable laying condition.

The relationship between the current path and effected ELCB is described below.

(1) High frequency leakage current path of inverter use circuit only
The current path indicated by (1) in *Fig. 4* is the case which occurs most generally. ELCB1 and ELCB2 are effected.

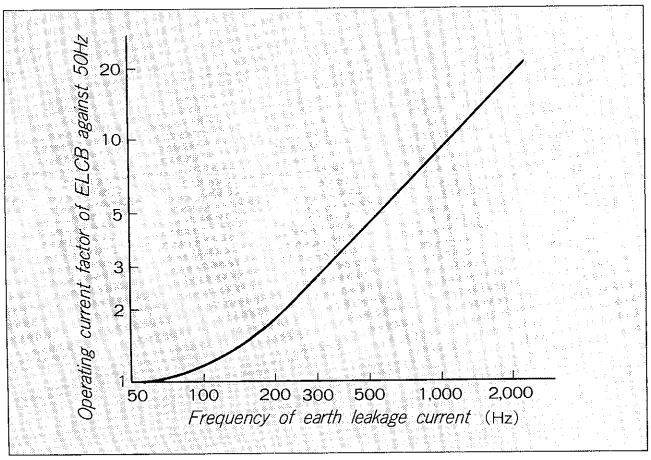
(2) High frequency leakage current path to other circuits
The current path indicated by (2) in *Fig. 4* shows the case when the high frequency leakage current flows through the capacitance between cables C1 of the inverter use circuit and circuit that does not use the inverter. ELCB2 and ELCB3 are effected.
When both cables are laid in proximity over a long distance and the capacitance between cables C1 is large, this current path must be considered.
The current path indicated by (3) in *Fig. 4* shows the effect on circuits that do not use an inverter and is an example which has an effect through the earth capacity Co of both cables. In this case, ELCB2 and ELCB4 are effected.
When a current path to other circuits that do not use an inverter exits and the ELCB was operated, there are many cases which require time to locate the cause. In such cases, the cable laying conditions and system flow chart must be compared and these current paths ascertained.

3. ELCB CHARACTERISTIC IMPROVEMENT AND SELECTION OF ELCB SENSITIVITY

3.1 ELCB operation characteristics improvement

Figure 5 is the internal circuit block diagram of the ELCB whose characteristics have already been improved. The improved part was making the low pass filter that is inserted between the ZCT and amplifier circuit more suitable by increasing it from one stage to two stages. *Figure 6* shows the change of the ELCB operating current when the frequency of the leakage current was raised. From the standpoint of preventing nuisance tripping of the ELCB, making the value of the operating current at high frequency

Fig. 6 Change of leakage current frequency and ELCB operating current



earth leakage current as high as possible is desirable. The operating characteristic after improvement was improved so that the value of the operating current at high frequency earth leakage current is larger than that before improvement. However, from the standpoint of electric shock protection which is the mission of the ELCB, making the value of the operating current at high frequency earth leakage current is undesirable. For these opposing problems, the problem of safety against electric shock at high frequency voltage was considered in deciding the characteristics.

3.2 Safety at high frequency

Regarding the danger limit of current for the human body when exposed to electric shock, threshold of ventricular fibrillation 50mA. sec used in deciding the sensitivity and time characteristics of ELCB is generally known

Table 1 Selection guide table of sensitivity at Fuji ELCB inverter circuit application

(a) AC200V 3-phase induction motor

Motor output (kW)	Full load current (A) (Note 1)	Inverter capacity (kVA) (Note 2)	Cable size (mm^2) Minimum-maximum	Cable length and applicable sensitivity					
				10m	30m	50m	100m	200m	300m
1.5	6.5	3	2 ~ 14						
2.2	9.2	3	2 ~ 14						
3.7	14.5	5	3.5~ 14	30mA					
5.5	21	8	5.5~ 14						
7.5	29	10	8 ~ 38						
11	42	15	14 ~ 38				100mA		
15	57	20	22 ~ 60						
18.5	70	24	30 ~ 60					200mA	
22	82	30	38 ~ 60						
30	106	37	60 ~125						
37	135	47	80 ~125						500mA
45	164	57	~325						
55	200	70	~325						

(b) AC415V 3-phase induction motor

Motor output (kW)	Full load current (A) (Note 1)	Inverter capacity (kVA) (Note 2)	Cable size (mm^2) Minimum-maximum	Cable length and applicable sensitivity					
				10m	30m	50m	100m	200m	300m
5.5	10.5	10	3.5~ 14						
7.5	14.5	10	3.5~ 14	30mA					
11	21	24	5.5~ 14						
15	28.5	24	8 ~ 38						
18	35	24	14 ~ 38		100mA				
22	41	47	14 ~ 38				200mA		
30	53	47	22 ~ 60						
37	68	47	30 ~ 60						
45	82	70	38 ~ 60					500mA	
55	100	70	60 ~125						
75	131	95	80 ~125						1,000mA
90	157	140	~325						(Special)
110	190	140	~325						

(Note 1) Value for Fuji Electric standard motor
(Note 2) Fuji Electric inverter FVR-P, FRENIC5000P, FRENIC5000G

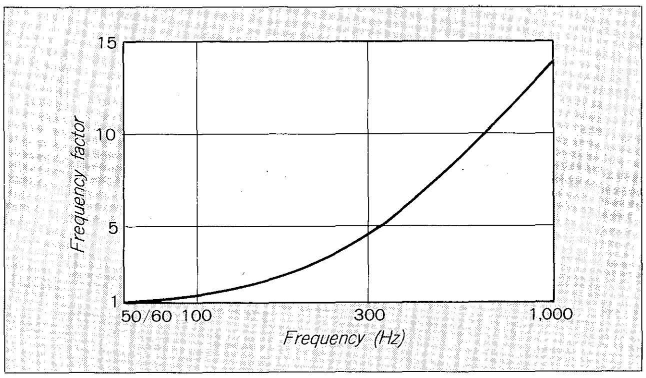


Fig. 7 Change of threshold of ventricular fibrillation with 50/60Hz as standard

around the world. However, this value is the value at the commercial power frequency.

IEC479-2 (Effects of current passing through the human body. Part 2: Special aspects) clarified the effects of frequency on the human body as shown in *Fig. 7*. The operating current rate of change versus frequency of Fuji Electric ELCBs is on the safe side of the rate of change of the safe limit of the human body by IEC.

3.3 ELCB selection guide table

Sensitivity selection at general circuits is based on the relationship with the protection earthing current of the equipment and calculation of the usual earth leakage current of the ELCB load side. However, besides the difficulty of calculating the usual earth-leakage current, finding the relationship with the operating characteristic of the ELCB is very difficult. Therefore, Fuji Electric prepared the sensitivity selection guide table at inverter application shown in *Table 1* for convenient selection.

This selection guide table was prepared by calculating the cable length by ELCB rated sensitivity current based on the test data with the ELCB and inverter combined. When using this table to select the sensitivity, the following should be considered:

(1) Cable length
Represents the total distance from the inverter to the motor. Therefore, when multiple motors operate under one inverter, the sum of the distances of the branch circuits as shown in *Fig. 8* is necessary.

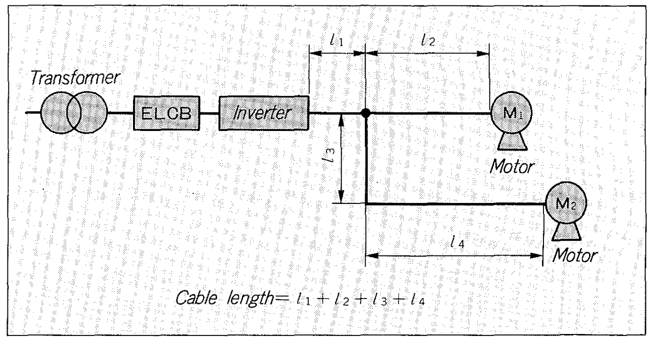


Fig. 8 Cable length when multiple motor operated

(2) Kind of cable
Since calculation is based on the earth capacity of 600V grade polyvinyl chloride insulation wire, when cable with an earth capacity smaller than 600V grade polyvinyl chloride insulation wire was used, the cable length can be extended in inverse proportion to the reduction ratio.

(3) Cable laying condition
Since calculation is performed by laying with laying by metallic (earthed), for smaller earth capacity laying conditions, such as when the cable was floated from the earth, the cable length can be extended.

4. CONCLUSION

Inverters are expected to be increasingly popular in the future. The authors will be happy if this article serves as reference for users when selecting an ELCB for inverter circuits.

BIBLIOGRAPHY

(1) IEC479-2 (Effects of current passing through the human body, Part 2: Special aspects), Chapter 4, *Fig. 11*

(2) Fuji inverter technical notes, MHT221b, pp. 21–29 (1988)

(3) Fuji ELCB technical notes, EH251b, pp. 50–51 (1989)