Study of Fault Current Limiter Applied to Loop Distribution Network

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Abstract: -As discussed in the field of Smart Grid distribution network will change its characteristics from conventional power distribution to power exchange between distributed power generations and loads. The distribution network will be operated in loop configuration instead of present radial shape for getting higher availability and higher efficiency. Problems in such distribution network are increase of short circuit current and voltage sag. These problems will be solved by application of fault current limiter reported by authors. This paper reportslimitation of fault current limiter application and shows protection coordination with impedance relaythrough computer simulation.

Key-Words: -Fault current limiter, distribution network, voltage drop, protection relay

1 Introduction

Renewable energy as photovoltaic generation is rapidly increasing in distribution network for reduction of CO2 emission. The role of distribution network is changing from conventional power distribution line to power exchange line between distribution networks or between distributed power generations and loads. For getting higher availability and efficiency the distribution network will be operated in loop configuration instead of present radial configuration. Therefore, the short circuit current in the distribution network will be increased. Additionally suppression of instantaneous voltage sag is required for keeping better power quality.

It is considered that application of fault current limiter (FCL) will be one of countermeasures for suppression of short circuit current and voltage dip. Most studies have treated one FCL for application in power network to reduce short circuit current, and voltage sag was not discussed [1].

The application of FCL in viewpoint of short circuit current reduction and voltage sag suppression in a loop distribution network is reporter [2][3].

In this paper further study is carried out and two new results are reported, one is limitation of FCL application, and the other is effect on protection relay.

2 Loop Distribution Network

The conventional distribution network has radiated connection for preventing fault expansion. Normally distributed line feeders are not connected each other at the end of feeder. Fault on one feeder does not expand to adjacent feeders by opening a circuit breaker on the faulted feeder. However, a loop connection is not applied for restriction of fault expansion, it is expected that the loop distribution network has flexible operation ability. A large amount of renewable energy represented by photovoltaic generation will be connected in the distribution networks, the loop network will be a useful configuration.

Currently, there are some studies for the loop distribution network. They have been studied construction of loop distribution network for line loss minimization [4], and centralized voltage control of the loop distribution system with renewable energy sources [5]. There is no study report of short circuit current reduction and voltage dip suppression in the loop distribution network without authors work. In this paper, we examine application of FCL to loop distribution network that suppresses voltage dip and short circuit current.

Fig. 1 shows a loop distribution network. A distribution line is represented by a resister and a reactor, a switch is shown as CB. PV represents a photovoltaic power generation as one of renewable power source and connected with load.

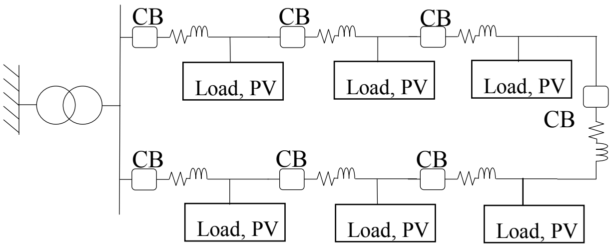

Fig. 1 Loop distribution network

A simpler network shown in Fig. 2 is used for the study, in which three FCLs are assumed. Two loads are assumed that contains PV. Parameters of this network are listed in Table 1. A transformer of distribution substation having 22kV and 6.6kV for a higher and a lower distribution voltage respectively is assumed and short circuit current of 13.8kA on 6.6kV side is assumed. The breaking capacity of the CB is assumed as 8kA, then the fault current exceeds the CB capacity, so FCL is required.

Table 1 Parameters of distribution network

Infinite-bus	Infinite-bus voltage [kV]	22
	Frequency [Hz]	50
	System inductance [mH]	2.82
	System resistance [mΩ]	8.87
Distributing substation Three-phase transformer	Primary side voltage [kV]	22
	Secondary side voltage [kV]	6.6
	Capacity [MVA]	30
	Reactance [%]	5
	Resistance [%]	0.1
	Short circuit current[kApeak]	13.8
Circuit breaker	Breaking capacity [kA]	8.0
	Operating time [ms]	200
Distribution line	Total line length [km]	5.5
	Line1 ~ 4(Each length 1.375km)	
	Inductance [mH]	0.418
	Resistance [Ω]	0.105
System load	Load1,2,3,4	
	Load current [A]	100
	Load capacity [MVA]	1.14
	Power factor	0.9

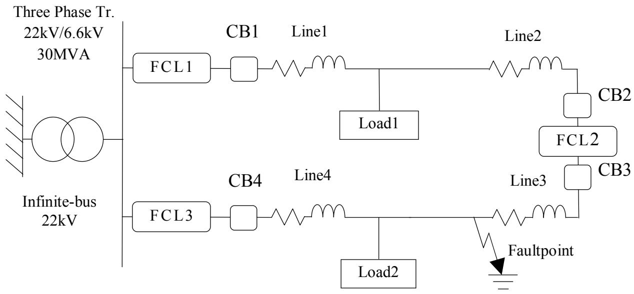

Fig. 2 Loop distribution network

3 Fault Current Limiter and Voltage Evaluation Curve

3.1 Fault Current Limiter

One phase of rectifier type FCL as shown in Fig. 3 is treated here. A dc reactor (DCL) is connected in a diode bridge (D1, D2, D3, D4). Usually the load current flows through diodes with the same current flow in the DCL, and no effect of DCL is obtained. When the load current increases due to fault, the current of the DCL also increases and current limiting effect by DCL is obtained.

A thyristor converter bridge is connected to DCL in series. The converter current is supplied through a single phase transformer connected to 6.6kV line. The dc current of the converter is detected and a dc current control is applied on it. This DCL current is named as a dc bias current here. The range of the firing angle is set from 0 degree to 180 degrees, the bridge permits power absorption. The bias current reference is set to a slightly larger than load current to prevent DCL effect during load current change in normal operation [6].

Parameter used in this study is listed in Table2. The inductance of DCL for FCL1 and FCL3 are selected to limit fault current less than 8kA at 0.2s after three phase fault. The bias current for both FCL is set to 400A that is larger than peak of the load current. The inductance of FCL2 is selected to larger than FCL1 and FCL2 to keep voltage at healthy line explained in the next paragraph. The bias current of FCL2 is 230A that is larger than the load current through FCL2.

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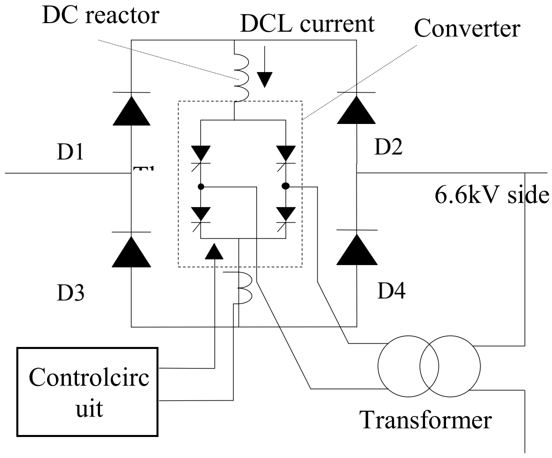
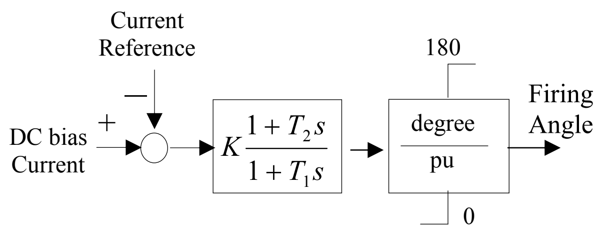


(a) Main circuit



(b) Control block

Fig.3 Fault current limiter of rectifier type with current control

3.2 Voltage evaluation curve

As a restriction for distribution network voltage ITIC curve [7] is referred for this study. This curve shows acceptable voltage for electronics equipment without interruption in operation. PV and other renewable power generation system will have the low voltage ride through performance, then wider voltage change will be accepted. In this study to keep operation of load and PV as possible as it can Fig. 4 is applied for the restriction, i.e. over 0.7pu during 0.5s.

4 Application of FCL

4.1 Three FCLs

Application of three FCLs is considered here as shown in Fig. 5. Two FCLs, FCL1 and FCL3, are located at start point of feeders. The one, FCL2, is located at connection point of these feeders. The inductance of DCL in FCL1 and FCL2 is selected to limit fault current less than the capacity of CB.

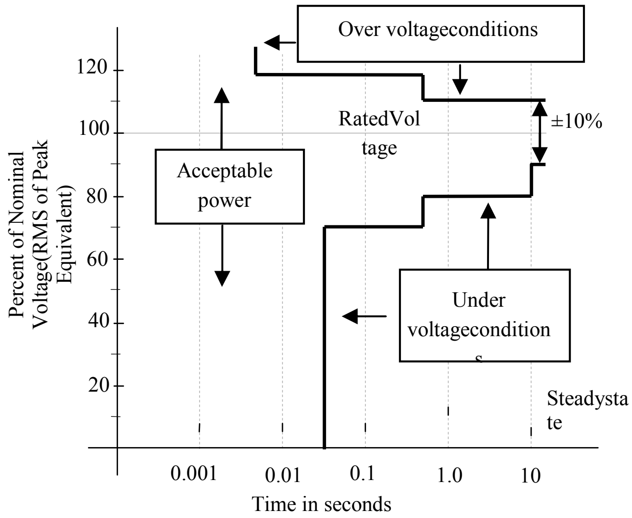


Fig. 4 ITIC curve

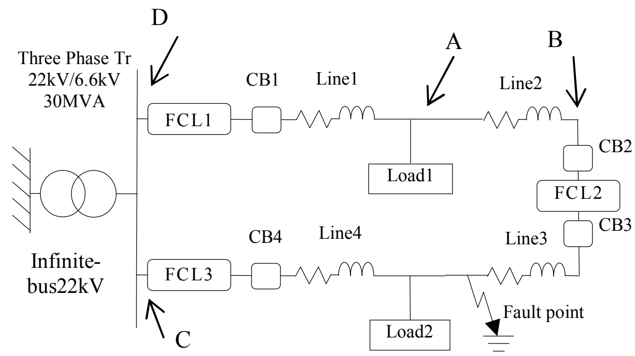


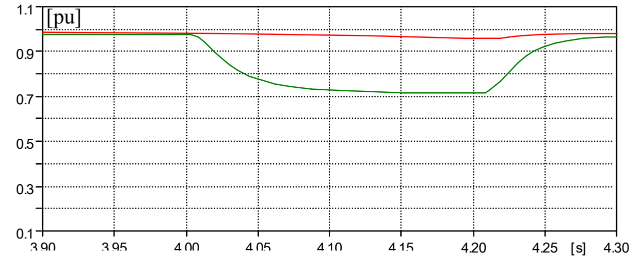
Fig.5Three FCLs application

The determination of DCL in DCL2 is explained here. The voltage at Load1 when a fault is assumed at Load2 in Fig. 2 is obtained as (1). Where E is the voltage at the substation, Xi is line reactance, and X_{FCL} is DCL reactance.

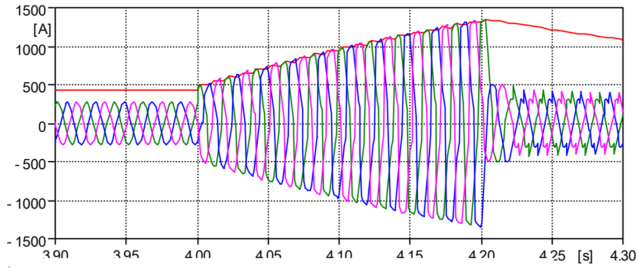
$$V_{load1} = \frac{X_{FCL2} + X_2}{X_{FCL1} + X_1 + X_{FCL2} + X_2} E \cong \frac{X_{FCL2}}{X_{FCL1} + X_{FCL2}} E \qquad (1)$$

The reactance of DCL2 is obtained as (2) under the condition of the voltage of 0.8pu is applied instead of 0.7pu mentioned above.

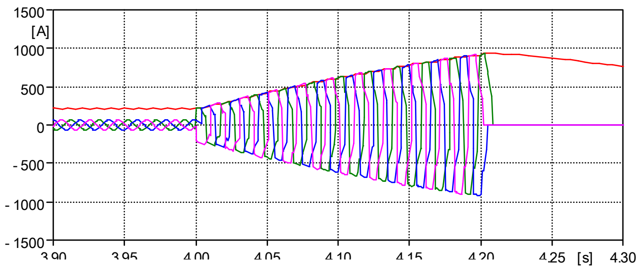
$$X_{FCL2} = \frac{V_{Load1} \times X_{FCL1}}{E - V_{Load1}} = \frac{0.8pu \times 100mH}{1pu - 0.8pu} = 400mH \qquad (2)$$



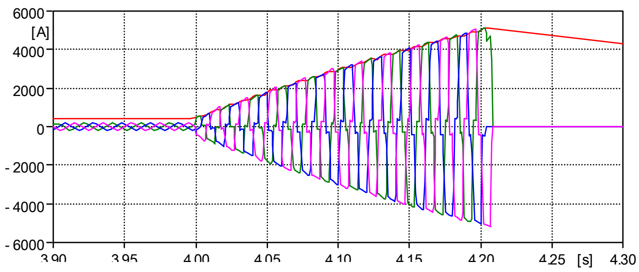
(a) Voltages



(b) FCL1 currents



(c) FCL2 currents



(d) FCL3 currents

Fig. 6 Voltages and currents

Fig. 6 shows simulation results. Three phases fault is applied at 4s and the fault is cleared at 4.2s. Fig. 6(a) shows voltages of the substation, Load1, and Load2. The voltage of Load1 remains over 0.7pu. Fig. 6(b) shows three phase currents of FCL1 and DCL current, after fault the load currents increases linearly by DCL in FCL1. Fig. 6(c) shows also three phase currents and DCL current in FCL2. Fig. 6(d) shows currents in FCL3. The voltage of LOAD1 is higher than 0.7pu, so Load1 can stay in operation during fault. This is a big advantage due to FCL.

Table 2 Parameters of Fault Current Limiter

Fault current limiter 1 and 3		
Rectifier circuit	DC reactor [mH]	100
	Resistive component of reactor [Ω]	0.157
	Diode resistance [mΩ]	3.12
Thyristor converter	Thyristor resistance [mΩ]	3.12
	Bias current [A]	400
	Fundamental current [Apeak]	22.4
Transformer	Transformer capacity [kVA]	110
	Reactance [%]	5
	Primary side voltage [V]	6600
	Converter side voltage [V]	145
Fault current limiter 2		
Rectifier circuit	DC reactor [mH]	500
	Resistive component of reactor [Ω]	0.785
	Diode resistance [mΩ]	3.12
Thyristor converter	Thyristor resistance [mΩ]	3.12
	Bias current [A]	230
	Fundamental current [Apeak]	108.8
Transformer	Transformer capacity [kVA]	510
	Reactance [%]	5
	Primary side voltage [V]	6600
	Converter side voltage [V]	705

4.2 Four FCLs

Application of FCL for more than three does not give desired performance in view point of fault current suppression and voltage dip prevention. Fig. 7 shows four FCLs application. If a fault is applied at Load3, the same good results are obtained. But if a fault is applied at Load2, the fault current through FCL3 is well suppressed butthe voltage at Load3 cannot maintain certain value. The voltage at Load2 is represented as (3), if X_{FCL1}=100mH, X_{FCL2}=X_{FCL3}=500mH, Vload2 reaches around 0.45pu.

$$V_{load2} = \frac{X_{FCL3}}{X_{FCL1} + X_{FCL2} + X_{FCL3}} E \qquad (3)$$

This situation appears for cascaded connection of FCL. The fault current suppression can be obtained, but voltage drop suppression cannot be obtained. This means the application of FCL will have limitation.

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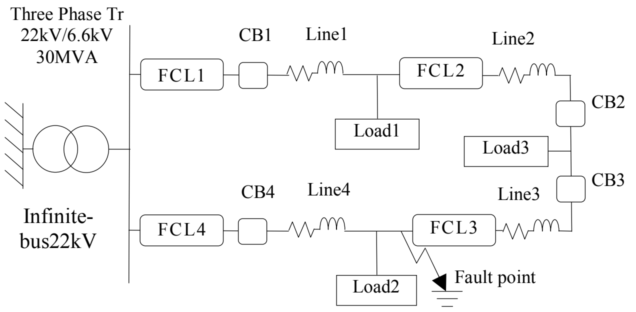

Fig. 7Four FCLs application

5 Coordination with Relay for three FCLs application

The effect on an impedance relay in the distribution network is examined in this section. The three FCLs application is used in this analysis, Impedances are calculated for four points in Fig. 2, A, B, C, and D, and they are shown in Fig.7 and Table 3. The impedance is calculated by V/I after converted to rms values.

According to Table 3 under the condition of with FCL it is observed that calculated impedances are corresponding to inductance of FCL. Comparing to the impedances without FCL, it is estimated that conventional impedance relay will be applicable to these FCL application.

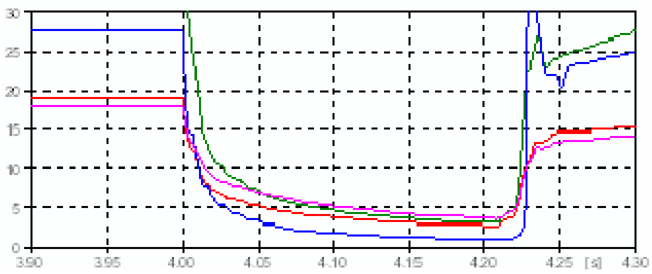

Fig. 8 Calculated impedances

Table 3 Calculated impedances at t=4.2s

Measured point		A	B	C	D
Impedance Z[ohm]	With FCL	2.67	2.98	0.97	3.68
	Without FCL	0.66	0.34	0.0	0.66

6 Conclusion

This paper proposed new application of FCL to loop distribution network. It showed that the fault current could be suppressed and the voltages were maintained by three sets application of FCL, andalso impedance relay would be applicable to the network including FCL. This paper alsoshowed the application of more than three FCLs does not give an expected performance.

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