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Effects of Type and Amount of Fault Current Limiter Impedance on Stability of System after Short Circuit Fault Occurrence in the Network

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Abstract
Due to expansion of power network, the short circuit current of power system are increased. Fault current limiters (FCL) are responsible to reduce and limit the fault currents. In addition, these components can also improve the stability of system. In this paper the effect of type and amount of FCL impedance on angle stability power system is investigated. Furthermore, the indices of rotor mechanical angle generator, when it reaches the steady state, after oscillations due to the fault occurrence for two types of FCL impedance (resistant and inductance) are being studied. Based on these indices, the amount of optimum FCL impedance for both resistant and inductance FCL are simulated and calculated on a tested network using a developed computer program.

Keywords: Terms—Fault Current Limiters (FCLs), System Stability, Short Circuit Fault, FCL impedance.

1. INTRODUCTION

The rise in producing and consuming electrical energy cause the transmission network and electricity distribution extension. Networks internal connection, installing series of capacitors and building parallel lines, cause loss reduction, increase in power transmission and increase in system's reliability and can cause rise in number of fault and rise in short circuit currents [1]–[8].

Flowed fault current, cause creation mechanical and thermal stress in system's equipment like transformers, overhead lines, cables and switches [5]–[10]. Power switches prevent equipment damaging by disrupting these currents. But building switches and other equipment based on short circuit current is not considered as an appropriate and ideal solution because the cost of this equipment in comparison with weaker equipment is more expensive and also it's not possible to destroy destructive effects of short circuit current on power networks [3]. Hence, experts had thought of building equipment, to limit short circuit current. Range of short circuit depends on equivalent Thevenin impedance from fault occurrence location. Hence, the basis of these methods is reducing the range of short circuit in proportion to increase equivalent Thevenin impedance from the fault location [5], [11]. Limiting fault current equipment are called Fault current limiters (FCL) [1], [5].

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FCLs other than reducing fault current also have other advantages including improving system stability [3], [6], [12], [13] reducing rate of rise of recovery voltage (RRRV) of power circuit breakers [11], improving power quality [14], reducing potential drop [3], [14], increasing reliability [3], [15], [16]. Including FCLs disadvantages, cause disturbance in network protective system that for solving this problem, relays are being reset [14], [17].

This paper shows that though the main target of installing FCL is reducing system's fault current, this equipment can cause system stability improvement and network potential drop reduction. Level of this effect is different based on the amount and type of FCL impedance in the terms of resistive or inductive.

This paper is formed of 5 sections. In the first part, an introduction about necessity of optimization and briefly about works done on the FCL in previous papers and this paper has been represented. In part two, different types of FCL and its performance have been represented and a simple model for using in this paper has been represented. In part three, a test network and its performance have been represented. In part four, taking account the different amounts of impedance for FCL, done short circuit test and its results have been represented. In part five, a total conclusion of paper has been represented.

2. FCL MODEL

In network normal condition, FCLs approximately don't show impedance but in fault condition, importing a series of impedance to the network, cause fault current limitation [4], [5], [18]. How to import and export this impedance based on the type of FCL and its structure is different and its impedance in some FCLs is variable. This impedance can be pure inductive, pure resistive or Combine them [3], [14], [18].

Different types of FCL are

FCLs based on PTC resistance [19].

1- FCLs by mechanical switches [20].
2- FCLs based on resonance circuit and Thyristor switch [7], [8], [10], [14].
3- Magnetic FCLs [1], [2].
4- Superconductor FCLs (SFCLs) [6], [9], [12], [15], [18].

SFCLs enter the system as soon as fault current incensement and limit the first cycle of fault current [4].

In this paper to modeling the FCL, pure resistive or inductive impedance employed a cycle post fault occurrence, in series to system circuit. This impedance after resolving fault or cutting troubled part of system, by two delay cycles returns to its normal state means impedance zero state. Figure (1) shows FCL condition pre and post fault that can represent each of FCL types. Represented model taking account the targets of the paper is proper and useful.

3. INTRODUCING the SAMPLE NETWORK and TEST SCENARIO

A. Introducing Tested Network

Test network that its single line diagram is shown in figure (2), includes two regional electricity systems (Area 1 and Area 2).

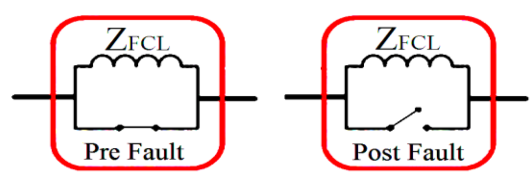

Fig. 1. Conditions of FCL from the left to the right, pre fault and post fault.

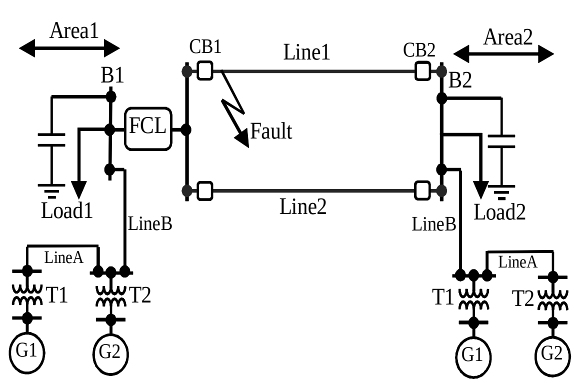

Fig. 2. Single line diagram of test system.

Each of these regions consist of two electrical energy generators (G1 and G2) and two transformers (T1 and T2) that are connected to buses B1 and B2 by energy transmission lines (line A and line B). These two buses are connected together by two parallel 220 kilometers line (line 1 and line 2) to make an electrical connection between these two regions. FCL installation location is considered between bus B1 and two transmission lines line 1 and line 2. Two loads with constant power (Load 1 and Load 2) are also connected to each bus B1 and B2. Characteristics of equipment are represented in chart (1). All equipment and lines of two regions are thoroughly the same and just the amounts of loads: Load1 and Load2 are different.

In simulating the system from model generator grade 7 contain stator dynamics, excitation field and damper winding are being used. Transformers are connected as star/delta, that this connection is around star generator and for modeling that, linear line transformer including resistor and winding's leakage inductance is used. Core magnetic characteristics are modeled as linear and with a parallel branch (arm) (Lm and Rm). About transmission lines, for two 220 Km line, accurate and perfect model of transmission line is used and for two short 10 Km and 25 Km lines fault π model is used. Fault is also a symmetric three phase short circuit by impedance equal to zero. Figures (3) and (4) show system's diagram modeled in MATLAB software.

Table 1. ***Units for Magnetic Properties*.**

Tdo'=8 Tdo'''=0.3 Tqo'=0.4 Tqo''=0.05 (s)	**Xd=1.8 pu Xd'=0.3 pu Xd''=0.25pu Xq=1.7 pu Xq'=0.55pu Xq''=0.25pu**	**Generators 900MVA 20kV, 60 Hz Xl=0.2 pu**
V2=230kV R2=1e-6 (pu) L2=0.15 (pu)	V1=20kV R1=1e-6 (pu) L1=0 (pu) Rm=Lm=500 pu	Transformers T1&T2 900MVA 60Hz
For Area 1&2 LineA=25(km) LineB=10(km)	R=0.0529 Ohm/km L=0.0014032 (H/km) C=8.7749e-9 F/km	Transmission lines 2 Lines from buses B1 to B2=220(km)
Qc=387MVAR	P1=967MW Q1=100MVAR	Load1
Qc=537MVAR	P2=1600MW Q2=100MVAR	Load2

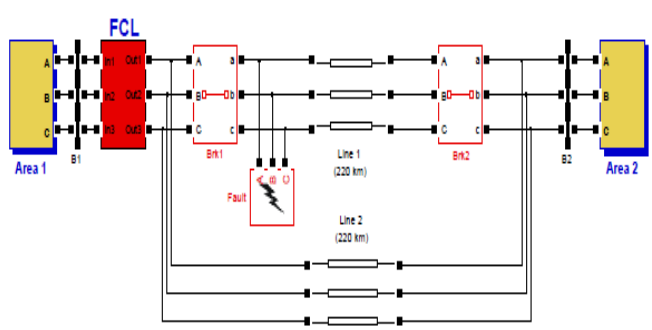

Fig. 3. Test system and connection lines between two 1 and 2 regions.

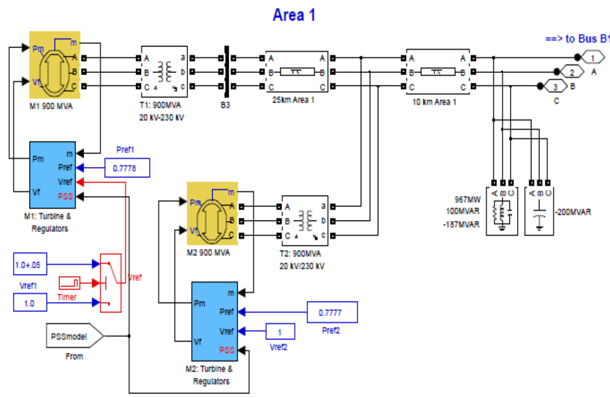

Fig. 4. Region 1 power network and its equipment.

B. Test's Scenario

The test scenario is like this that a symmetric three phase short circuit happens in the point shown in figure (2). One cycle after fault occurrence, FCL enters the circuit and the ZFCL impedance is set in the circuit to limit fault current. At the same time protective relays specify fault occurrence and cut command is sent to switches set in two sides of fault location. Switches work after 200ms and the fault point will be separated. After resolving the fault, it takes two cycles that FCL returns to its normal state and system got its new normal state.

Test process for different amounts of resistive or inductive impedance for FCL has been done that taking account that three phase short circuit occurrence in network and also amount and type of FCL impedance, maximum rate of deviation of generator bus angle (ΔΘ) in terms of degree and also period of angular fluctuations attenuation (ts) in terms of second is calculated. For choosing attenuation period ts it is calculated like angular fluctuation should be in the range of 2 percentages less or more than final amount.

4. RESULT OF THE TEST ON SAMPLE NETWORK

First, it is considered that FCL is not in the network means FCL impedance equals to zero. Figure (5) shows angle fluctuations curve for both generators of region one (G1 and G2) without FCL. Fault occurred in sixth second and power switches separate fault transmission line from the entire network after 200ms. It is observed that in the mood without FCL system is unstable and the amount of generator bus angle deviation tends to infinite.

To make the system be stable, a FCL is installed in the network. By installing a FCL with impedance equal to ZFCL=1+i12, it is observed that after fault occurrence the amount of generator bus angle deviation is affected by fluctuation but after a while again returns to stable state. Hence, network becomes stable by presence of FCL. Figure (6) shows fluctuations of generator bus angle deviation G1 in proportion to time. The reason of choosing generator G1 is that its bus angle deviation amount is larger than other generators. Taking account the figure, the amount of generator bus angle deviation G1 for pre and post fault in system stable conditions equal to 29 and 5.55 degree respectively. The period of angle fluctuation attenuation (tsG1) equals to 13 minus 6 seconds. Also the maximum amount of this generator bus angle deviation (ΔΘG1Max) equals to 2.116 degree in this condition.

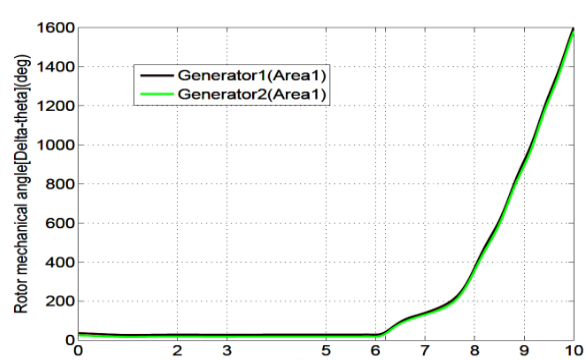

Fig. 5. Generator bus angle deviation-without FCL.

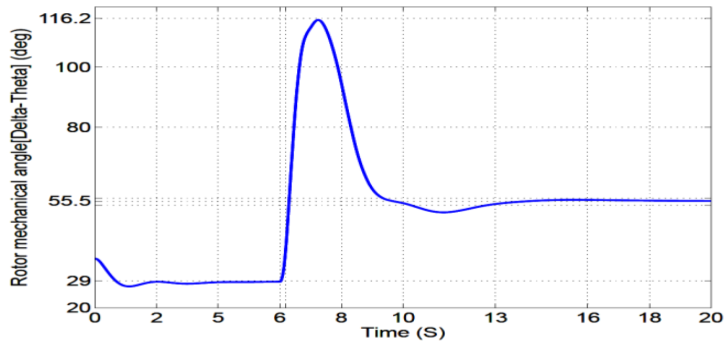

Fig. 6. Generator bus angle deviation curve G1 of region 1.

For studying the effect of type and amount of FCL impedance on stability indicators, two kinds of FCL which are resistive and inductive are considered and the amounts of indicators ΔΘG1Max and tsG1 taking account the resistive amounts of FCL impedance are calculated. Figures (7) and (8) and also chart (2) show the result of test for different amounts of FCL impedance.

Figure (7) shows that by increasing the impedance for both types of FCL, first ΔΘG1Max indicator will decrease in a way that for resistive FCL by considering R=7.25, reaches its mini mum amount equals to 72.4 degree and for inductive FCL by considering L=200mH and impedance Z=i75.4 Ω reaches to 84.2 degree. But after this amount, by increasing FCL impedance, the process of ΔΘG1Max reduction stops and starts increasing that in R=16.5 Ω or L=470mH system enters angular instability.

Rate of reduction and incensement the angular fluctuation degradation (tsG1) in figure (8) is approximately similar to diagram ΔΘG1Max. So that approximately in that point that we observe more reduction of ΔΘG1Max, less time tsG1 wills occur.

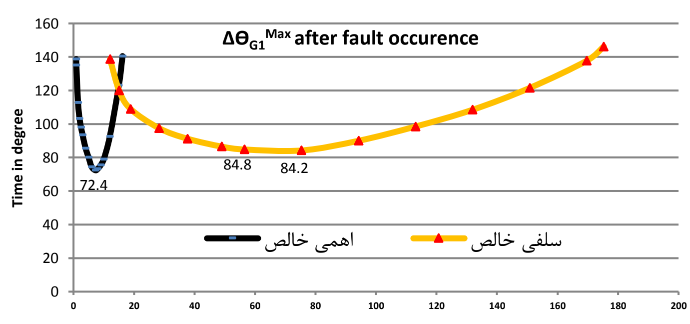

Fig. 7. The amount of ΔΘG1Max taking account the amount of FCL impedance.

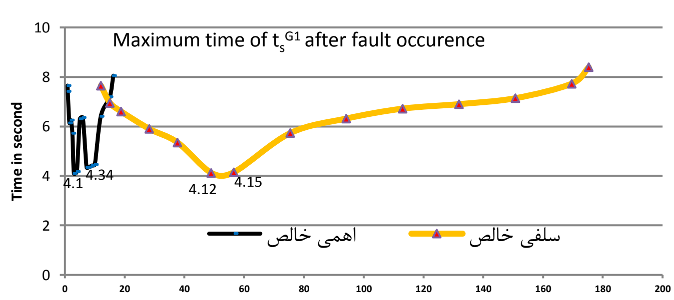

Fig. 8. Time of fluctuations degradation tsG1 taking account the FCL impedance.

Table 2. ***Units for Magnetic Properties.***

Resistive FCL (Ohm)	$\Delta\Theta_{G1}^{Max}$ for R_{FCL}	t_s^{G1} for R_{FCL}	Inductive FCL (Ohm)	$\Delta\Theta_{G1}^{Max}$ for X_{FCL}	t_s^{G1} for X_{FCL}
0	Inf	Inf	0	Inf	Inf
0.9	138.7	7.65	11.31	Inf	Inf
1.5	112.7	6.14	12.06	138.7	7.65
2	103.2	6.25	15.08	120	6.95
2.5	98	5.72	18.85	109	6.6
3	93.5	4.1	28.27	97.5	5.9
4	85.5	4.18	37.70	91.2	5.35
5	80	6.3	49.01	86.5	4.12
6	74.4	6.35	56.55	84.8	4.15
7.25	72.4	4.34	75.40	84.2	5.73
8	73.2	4.35	94.25	90	6.32
9	75.5	4.42	113.1	98.5	6.72
10	79	4.46	132	108.5	6.9
12	92.5	6.41	150.8	121.5	7.14
15	123	7.19	169.7	137.7	7.73
16.2	140.5	8.05	175.3	146.2	8.39
16.5	Inf	Inf	177.2	Inf	Inf

Rate of reduction and incensement the angular fluctuation degradation (tsG1) in figure (8) is approximately similar to diagram ΔΘG1Max. So that approximately in that point that we observe more reduction of ΔΘG1Max, less time tsG1 wills occur.

Results of analysis, reveals two important points. First, resistive FCL even in low amounts of impedance can strongly cause system stability but for guarantying system's stability by an inductive FCL, higher impedance is required. Resistive FCL can reach the least amount of ΔΘG1Max equals to 72.4 degree, while by an inductive FCL in the best position reaches to 84.2 degree that in comparison with resistive FCL is worst.

Second, though FCLs can cause system stability, but if FCL impedance was higher that a specific amount, not only couldn't cause system stability but also could cause system instability. Hence, taking account the higher amount of FCL impedance, the more fault current reduction and in the impedances higher than FCL angular instability may happen so, choosing the amount of FCL impedance based on more fault current reduction, can not necessarily lead to optimum choice and in system stability subject should be considered in FCL optimum impedance calculation. Figures (9) and (10), show angle fluctuation curve for first region generators G1 and G2 in the state of resistive impedance equals to R=7.25 Ω and inductive impedance equals to L=200mH and impedance equals to Z=i75.4 Ω.

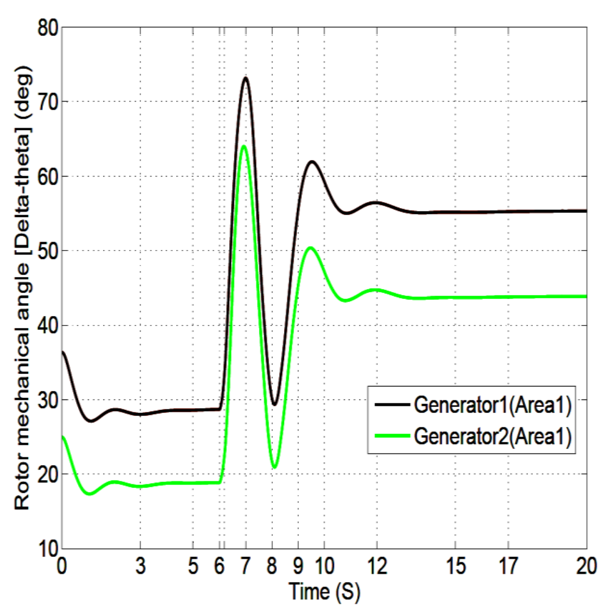

Fig. 9. Generator bus angle deviation with resistive FCL R=7.25 Ω.

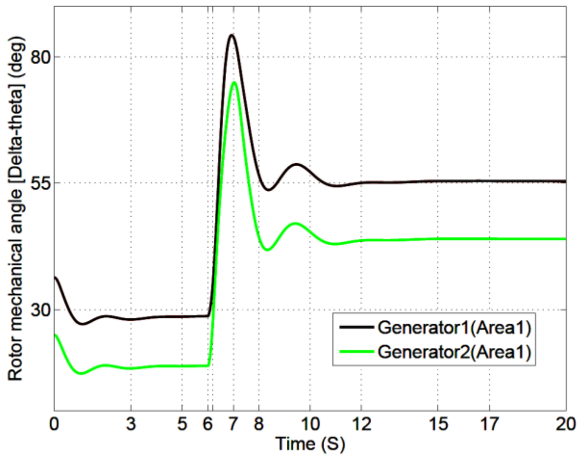

Fig. 10. Generator bus angle deviation with inductive FCL L=200mH.

5. CONCLUSION

This paper shows that adding FCL to system not only can effect short circuit currents reduction but also effects system angular stability strongly. In a way, the system which is affected by angular instability can be stable by adding a FCL. The result of test on two kinds of pure resistive and pure inductive FCL, shows that resistive FCL even by less amounts of resistance can cause system stability while, to stabilize the system by inductive FCL, bigger impedance is required in comparison with resistive FCL. Other than that and in best conditions for both types of FCL, maximum generator bus angle deviation range in resistive FCL in comparison with inductive FCL, is 12-degree lower that shows resistive FCL is better in system stability.

The results of simulation show that choosing inappropriate FCL impedance not only don't lead to system stability improvement but also can cause system instability. Because maximum generator bus angle deviation, at first and by increasing FCL impedance, decreases but after passing pure impedance this flow becomes ascendant and cause system instability. This point is important because in some cases, for reaching the specific amount of fault current reduction, high amounts of FCL impedance is needed and can cause system instability.

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