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Optimal Protection Coordination of over current Relays in DG System with Solid State Fault Current Limiters

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Abstract:
In order to meet the increase in the power demand, Distributed Generation (DG) system plays a major role. Apart from generation it also faces many technical challenges, loss of harmonic control, voltage regulation and losses and changes in the relay coordination due to differences in short-circuit levels. In a system when a short circuit takes place it leads to severe damage as very high magnitude of fault current will be observed. These high magnitude short circuit fault currents eventually leads to coordination problem of Over current relays. To achieve proper coordination, time settings between the relays are optimized using several optimization techniques.
In present circumstances, occurrence of fault in a system have become high which greatly affect reliability of power system. To avoid discontinuities in the system, optimal relay time settings have to be determined which are associated with the fault current that has to be minimized. Here, in order to limit the transient fault current in the system, solid state fault current limiter (SSFCL) is designed. To determine the optimal relay time settings, a new optimization technique, hybrid PSOGSA is applied.
The reduction in the fault current magnitudes have been observed: without and with SSFCL. Proposed optimization technique has been evaluated by comparing the results for the system with and without DG. The programming is done in MATLAB software and was implemented on 4bus DG system in SIMULINK platform.

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I. Introduction

Energy requirement in the world has been increasing at a faster rate which is achieved by placing DG into the system [1]. To achieve reliability of the power system protection coordination plays a vital part.

However, when DG is incorporated then the system undergoes several changes, due to differences in fault current magnitude and the bidirectional flow of power causes relay coordination problem [2].

Radial system is most widely used type of distribution system. Among various protective devices, relays assure faster operation, low maintenance and long durable life where Overcurrent relay protection plays a major role. To achieve proper coordination between the relays, the time settings of the relays have to be determined accurately so that primary relay senses and operates first as soon as the fault occurs. The optimal values of Time setting Multiplier (TMS) and Plug Setting (PS) have to be determined to minimize the relays total operating time. Objective function considered here is a constrained optimization where certain bounds are kept on values of pick up current, plug setting and operating times of relays which is briefly discussed in section 2.

To limit the effect of DG on OC relay coordination, Solid State Fault Current limiter is used to stabilize the system operation. During fault condition, it reduces the fault current magnitude to an acceptable value. And in addition, Particle SwarmOptimization- Gravitational Search Algorithm (PSOGSA)was implemented in order to determine the optimal time settings.

II. Proposed Solid State Fault Current Limiter:

At normal operating state, SSFCL has low voltage drop, less power loss and it inserts low impedance to the system. Whereas if a fault occurs then it reduces high magnitude transient fault current and provides high impedance to the network. It is required to withstand the fault condition for a sufficient time. It improves power quality and stability of the system.Modeling of SSFCL as in Fig.2.1 consistsof control system which is needed to generate triggering pulses for thyristors[3],[4].Fault Current identification is performed by estimating the preset value of current with that of the RMS value.

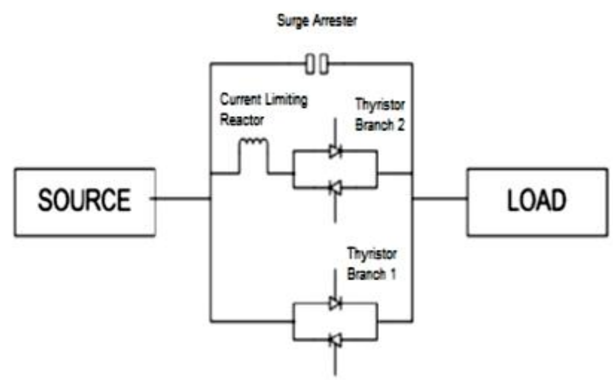

Fig.2.1. Arrangement of SSFCL

The design of SSFCL primarily constitutestwo solid state switches connected in inversely parallel manner [5]. One pair consists of thyristorswhereas the other one consists of thyristor with current limiting reactor in series which limits the detected fault current to a reasonable value [6]. To minimize the effects of switching overvoltage surges on the system, a surge arrester is placed in parallel. To place the current limiting reactor in the system,its valuehas to be determined. Its value is obtained by equalizingthe FCL impedancemagnitude with the inductive reactance of the limiting reactor.

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$$|Z_{FCL}|=|\omega L_{FCL}|=\frac{\overline{V}}{I_{FCL}} \quad (1)$$

Where, L_{FCL} is limiting reactor inductance, Z_{FCL} is limiting reactor impedance, I_{FCL} is the fundamental fault current,$\overline{V}$ is the phase voltage magnitude.

OC Relay coordination in radial system:

To maintain reliability of the system, proper coordination has to be achieved between the relays. Whenever a fault occurs at a particular point, relay nearer to that point should operate first and remove it as fast as possible. So, the main objective function is to obtain the minimal operating time of relay[7],[8] which is given as,

$$\text{Min } s = \sum_{i=1}^{n} t_{i,k} \quad (2)$$

Where, $t_{i,k}$ is ith relay operating timefor fault in kth zone and n is total number of relays present in the system.

Limits on pick up current:

Maximum value of load current observed by each operating relay determines minimum value of relay operating current which is termed as pick up current and vice versa. Bounds are also kept on relay plug setting so that it is maintained between maximum and minimum values.

$$I_{pmin} \le I_p \le I_{p\,max}$$

$$P_{Smin} \le P_S \le P_{Smax} \quad (3)$$

2.1.2 Characteristics of relay:

$$t_{op} = \frac{\lambda\ (TMS)}{(PSM)^{\gamma}-1} \quad (4)$$

$$t_{op} = \frac{0.14(TMS)}{(\frac{I_{relay}}{PS} * CT\ sed\ rated\ )^{0.02} - 1} \quad (5)$$

where, t_{op} is operating time of relay , PS is the plug setting of relay , TMS is relay time multiplier setting,I_{relay} is reduced magnitude of fault currentseen by relay, and CT sec rated is the CT secondary rated current.Here, IDMT relay is considered whose characteristic values are γ is 0.02, and λ is 0.14. The values of TMS and PS are found using hybrid PSOGSA.

III. Over Current Relay Coordination throughOptimization Techniques:

3.1Gravitational Search Algorithm (GSA):
GSA is a population-based heuristic algorithm which depends on law of gravity and mass interactions. Agents, which are termed as solutions, interact with other agents with gravitational force. In a particular population the activity of each agent is determined by their own mass where all of them are defined to have variable mass [9]. Best solution is obtained for the object having heavier mass. Controllability of velocity of a body is assured by these masses. After evaluating all the agents in a population best and the worst agents are assigned. The fitness value determined evaluates the values of these parameters[10].

3.2Particle Swarm Optimization (PSO):
It is a population-based technique based on intelligence and swarm movement.Each

individual is termed as particle and group of particles constitute swarm .These particle move around through the solution space, searcing for thebest value [11]. With reference to distance between its positional best and current position and, the distance between its current position and its global best ; each and every particle in the search space attemps to modify its current position.

3.3 Hybrid PSOGSA:
Hybridizationprocedure ofany twoalgorithmswill bedone at a high level or low level with relay or co-evolutionary method which is known as homogeneous or heterogeneous [12].Here,PSO and GSA are hybridized with the help of alow-levelco-evolutionaryheterogeneous hybrid technique. The main aim of developing hybrid PSOGSA is to combine upglobal search capability (g_{best}) in PSO with the local search capability(p_{best}) in GSA. As the functionality of both algorithms is combined, hybrid here is low level. Both the algorithms run in parallel hence it is known as co-evolutionary.To achieve hybridization, agents which are known to be candidate solution will be initialized first.When a better solution is obtained, the agents near the solution attempt to attract the remaining other agents. Finally all the agents move slowly when they combinedlyapproach nearer to a good solution. In hybrid PSOGSA, each agent has the capability to identify the so far obtained best solution, finally it starts to move towards the best solution. From the obtained values of acceleration, mass and force between the agents, velocity and position are updated which are calculated from PSO. In this manner, hybridization of two algorithms is carried out.

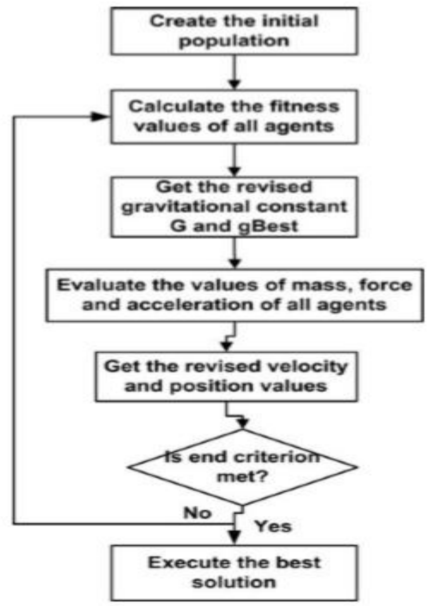

Fig.3.1 Hybrid PSOGSA Flowchart

IV. Simulation Results:

A four bus DG system was modeled to evaluate and minimize the effects of DG on over current relay coordination. The CT ratios of relays present in the system are given below.

Table: I Relay CT Ratio

Relay	Ratio of CT(A)
1	1000/1
2	800/1
3	600/1
4	600/1
5	600/1
6	600/1

Table: II LINE DATA:

Parameter	Value
Grid MVA	25MVA
Grid Voltage	161KV
Line length	100km

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Nominal frequency	50Hz
Transformer primary voltage	161KV
Transformer secondary voltage	11KV
Current limiting reactor	9.95mH

Various cases have been considered to all of which SSFCL is placed and reduction in the fault current magnitude is observed.

Four cases have been studied where to each case SSFCL is applied to determine the new fault current values for which a hybrid optimization technique PSOGSA is applied to determine TMS and PS values.

Table : III Values of Fault current without and with SSFCL

Case	Without SSFCL	With SSFCL
1.Without DG (1) R1 (2) R2	2552 A 66.13A	0.7217A 0.03129A
2.With DG at 20% (1) R1 (2)R2	2336A 2800A	0.7531A 4.106A
3.DG at 23.3% (1) R4 (2) R1 (3) R2	675.3A 610.1A 210A	0.9796A 1.146A 0A
4.DG at 26.6% (1) R4 (2) R1 (3) R2	875.3A 610.1A 210.1A	0.1631A 1.435A 0.1866A
5.DG at 30% (1) R4 (2) R1 (3) R3	120A 500A 500A	0.2847A 0.6946A 0.146A

Table: IVRelay operating time for fault at different location (without dg)

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	1.34	-	-	-
B	2	0.68	1	1.63	0.95
C	3	0.96	2	1.62	0.66
D	4	1.33	1	1.64	0.31
E	5	1.32	2	1.63	0.31
F	6	1.88	3	2.20	0.32

When SSFCL is placed in the system ,fault current magnitude is reduced and a new objective function is developed implementing hybrid PSOGSA technique through which better coordination between relays have been observed in table V and VII.

Table: VRelay operating time for different fault location(without dg) observed with hybrid PSOGSA by placing SSFCL

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.67	-	-	-
B	2	0.32	1	0.05	0.28
C	3	0.04	2	0.38	0.34
D	4	0.65	1	0.67	0.02
E	5	0.03	2	0.38	0.35
F	6	0.35	3	0.44	0.09

Table: VIRelay operating time for different fault location(withDG at 20% level)

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	1.27	-	-	-
B	2	0.67	1	1.27	0.60
C	3	0.36	2	1.01	0.65
D	4	0.49	1	1.25	0.76
D	4	0.49	2	0.95	0.46
E	5	0.50	2	1.01	0.51
F	6	0.62	3	0.97	0.35

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Table :VIIRelay operating time for system with DG at 20% level along with SSFCL observed with hybrid PSOGSA

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.90	-	-	-
B	2	0.77	1	0.90	0.12
C	3	0.13	2	1.26	1.13
D	4	0.58	1	0.90	0.32
E	5	1.12	2	0.77	0.34
F	6	0.53	3	0.83	0.30

Table: VIIIRelay operating time at 23.3% DG level

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	1.0225	-	-	-
B	2	0.7496	1	1.0533	0.3037
C	3	0.4809	2	0.7824	0.3015
D	4	0.5619	1	1.0522	0.4903
E	5	0.4013	2	0.7824	0.3811
F	6	0.2278	3	0.5310	0.3032

Table: IX Relay operating time at 26.6%DG level

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.9890	-	-	-
B	2	0.6902	1	1.0050	0.3148
C	3	0.4544	2	0.7706	0.3162
D	4	0.3573	1	1.0142	0.6569
E	5	0.3762	2	0.7753	0.3991
F	6	0.2299	3	0.5453	0.3154

Table: XRelay and CTI values when DG action is not taking place

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.4812	2	-	-
B	2	0.5592	1	0.5010	-0.0582
C	3	0.5499	2	0.5792	0.0293
D	4	0.3127	1	0.5010	0.1883
D	4	0.3127	2	-	-
E	5	0.4757	2	0.6443	0.1686
F	6	0.4473	3	0.5498	0.1025

In the above table X, CTI is violated. It is observed that for fault at D, E, F, it is a positive value which means the relays are able to isolate the fault. But for the cases where fault is created at locations A,B and C relay is not able to isolate the fault.

Similarly, for 26.6% penetration CTI values have been observed for LL and LLG fault in below table XI and table XII

Table: XIRelay operating time and CTI values at 26.6% DG level when LL fault occurs

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.7382	-	-	-
B	2	0.4751	1	0.7938	0.3187
C	3	0.3217	2	0.6127	0.2910
D	4	0.3075	1	0.7938	0.4863
E	5	0.3427	2	0.5116	0.1689
F	6	0.2142	3	0.4985	0.2843

Table.XIIRelay operating time and CTI values at 26.6% DGwhen LLG fault occurs

Fault Point	Primary Relay Unit		Back Up relay Unit		CTI(sec)
	Relay No.	Operating Time	Relay No.	Operating Time	
A	1	0.7270	-	-	-
B	2	0.4691	1	0.7938	0.3247
C	3	0.3015	2	0.5110	0.2095
D	4	0.3041	1	0.7938	0.4897
E	5	0.3354	2	0.5079	0.1725
F	6	0.2127	3	0.4887	0.2760

Table : XIIIRelay TMS and PS values using PSO and GSA(without DG)

Relay No.	TMS	PS
1	0.0840	0.9985
2	0.0800	1.0742
3	0.0800	1.2461
4	0.0803	1.1453
5	0.0919	1.1011
6	0.0801	1.0427

Total Operating Time (sec) using PSO 15.0026

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Relay No.	TMS	PS
1	0.1065	0.9924
2	0.0915	1.0018
3	0.1022	0.9955
4	0.1426	1.0919
5	0.0811	1.2316
6	0.0800	1.0202

Total Operating Time (sec) using GSA 14.5621

Table: XIVRelay TMS and PS values using GSA and PSO at 20% DG level

Relay No.	TMS	PS
1	0.0994	0.9275
2	0.1105	0.9292
3	0.1001	1.4399
4	0.0815	1.2607
5	0.1382	1.4144
6	0.0893	1.0374

Total Operating Time (sec) using GSA 9.2148

Relay No.	TMS	PS
1	0.1160	0.9179
2	0.0947	1.1522
3	0.1125	1.2630
4	0.2619	0.9106
5	0.0800	1.4318
6	0.0801	1.1449

Total Operating Time (sec) using PSO 10.7

Table: XVRelay TMS and PS values using GSA and PSO techniques at 23.3% DG level

Relay No.	TMS	PS
1	0.2882	0.1603
2	0.2227	0.1250
3	0.1323	0.2225
4	0.1285	0.2875
5	0.1060	0.2347
6	0.0801	0.1117

Total Operating Time (sec) using GSA 7.6

Relay No.	TMS	PS
1	0.3928	0.1003
2	0.2617	0.1037
3	0.1977	0.1201
4	0.1142	0.1808
5	0.0958	1.2928
6	0.0829	1.1529

Total Operating Time (sec) using PSO 8.1060
>> |

Table:XVIRelay TMS and PS values using GSA and PSO techniques at 26.6% DG level

Relay No.	TMS	PS
1	0.3380	0.1034
2	0.1792	0.1648
3	0.1248	0.2594
4	0.1271	0.1303
5	0.1076	0.2217
6	0.0831	0.1187

Total Operating Time (sec) using GSA 7.3090

Relay No.	TMS	PS
1	0.2933	0.1436
2	0.1827	0.1639
3	0.1282	0.2523
4	0.0841	0.3908
5	0.0969	0.3502
6	0.0802	0.1344

Total Operating Time (sec) using PSO 7.5151

V. Conclusion:

The effect of DG penetration on over current relay coordination was studied. Due to the presence of DG in the system, increased fault current magnitude was reduced by placing SSFCL in the system. The main objective function here is to reduce the relay operating time by determining the optimal time settings of over current relays. This is achieved by implementing hybrid PSOGSA technique on a four bus DG system and comparative analysis is done between PSO, GSA and hybrid PSOGSA techniques. It was observed that the relay operating time was minimum when hybrid PSOGSA technique was applied to the system.

REFERENCES:

1. P. P Barker and R.W. de Mello, “Determining the impact of distributed generation on power systems part I - Radial distribution systems,” IEEE Trans. Power Del., vol.15, pp.486-493, Apr. 2000.
2. A. Srivastava, J. M. Tripathi, Ram Krishnan andS.K. Parida,“Optimal Coordination of Overcurrent relays using Gravitational search algorithm with DG penetration,” IEEE Trans. On Industry Applications, Vol.54, no. 2, March/APRIL, 2018.
3. J.P. Sharma, VibhorChauhan and HR Kamath, “Modelling and Analysis of solid State Fault Current Limiter,” International Journal of Electrical, Electronics and Data Communication,vol.2, No.6, pp.9-13, June 2014.
4. V.K. Stood and S. ShahaburAlam, “3-phase Fault Current Limiter for distribution systems”. IEEE International conference on Power Electronics, Drives 2006.
5. M.M.A. Salama, H.Temraz, A.Y. Chikhani and M.A. Bayoumi,“Fault-Current Limiter with thyristor -controlled impedance”,IEEE Trans. on Power Delivery, Vol. 8, No. 3, July.
6. FabioTosato and Stefano Quaia,“Reducing Voltage Sags through fault current limitation”,IEEE Trans. on Power Delivery, Vol.16, No.1, January 2001.
7. A. Urdaneta, R. Nadira, and L.G. Perez Jimenez, “Optimal coordination of directional overcurrent relays in interconnected power systems,” IEEE Trans.on Power Delivery , vol.3, no.3,pp.903-911,July .1988.
8. P.P Bedekar, S.R. Bhide, and V.S. Kale, “Coordination of overcurrent relays in distribution system using linear programming problem,” in Proc. Int. Conf. Control Autom. Commun. Energy Conserv., Jun. 4-6, 2009.
9. A. Srivastava, J.M. Tripathi, S.R. Mohanty, and N. Kishor,“A simulation based comparative study of optimization techniques for relay coordination with distributed generation,” in Proc. IEEE Student Conf. Eng. Syst., Allahabad, India, May 2014.
10. S. Mirjalili and S.Z.M. Hashim, “A new hybrid PSOGSA algorithm for function optimization,” in Proc. Int. Conf. Comput. Inf. Appl., 2010, pp.374-377.
11. M. J. Damborg et al., “Computer aided transmission protection system design, Part I: algorithms,” IEEE Trans. Power App. Syst., vol.PAS-103, no.1, pp.51-59, Jan.1984.
12. A. Srivastava, J. Mani Tripathi and S.R. Mohanty&Bhagabat Panda(2016),“Over current relay coordination with distributed generation using hybrid PSOGSA,” Electric Power components and systems,44:5,506-517.