CAT SWARM OPTIMIZATION BASED SOLID STATE FAULT CURRENT LIMITER IN DISTRIBUTION SYSTEM

[1]S EDWIN JOSE, [2]S RAMARAJ,
[1]ASSOCIATE PROFESSOR, [2]ASSISTANT PROFESSOR
[1]DEPARTMENT OF EEE [2] DEPARTMENT OF EEE
[1]P.S.R.ENGINEERING COLLEGE, SIVAKASI, TAMILNADU, INDIA, [2]P.S.R.ENGINEERING COLLEGE, SIVAKASI, TAMILNADU, INDIA

***Abstract**:* This paper presents a modified bridge type flux-coupling non-superconducting fault current limiter (BSFC-NSFCL) for suppressing the fault current. A flux-coupling reactor and a bidirectional bridge switch are combined to perform the functions of steady-state line current sharing and fault current suppression. The proposed system is addressing a new and modern optimization tool such as cat swarm optimization (CSO) algorithm. It is generated by observing the behaviors of cats, and composed of two sub-models, i.e., tracing mode and seeking mode, which model upon the behaviors of cats. The modified CSO based BSFC-NSFCL mainly utilizes the magnetic flux cancellation effect to make the limiter behave as a short circuit on the circuit during normal operation. Hence, there is almost no impact on the power system when the limiter is used. When a fault event occurs, the bridge switch turns off immediately, and then the magnetic flux cancellation effect disappears. Thus, the impedance of primary coil inserts into the circuit to restrict the fault current phenomena. Once the fault is removed, the bridge switch turns on again, and the BSFC-NSFCL recovers to the normal operation. The output result have implemented the MATLAB and also prototype model hardware results are validated.

Index Terms **– CAT SWARM OPTIMIZATION, BSFC-NSFCL,MATLAB**

I. Introduction

In the recent years of power network cause the fault current of the system increased. The levels of short circuit current in many places have often exceeded the withstand capacity of existing power system equipment. A simplification to this matter; security, stability, and reliability of power system will be negatively affected. When a fault current of the power system to a safe level can reduce the risk of failure to the power system equipment due to high fault current flowing through the system. [1]. Due to, there is no surprise to fault current limiting technology has become a hotspot of fault protection research since this technology can limit the fault current to a low level. In this design view, limiting the fault current to a low level can reduce the design capacity of some electrical equipment in the power system. This will lead to the reduction to the investment cost for high capacity circuit breakers and construction of new transmission line. Consequently, from both technical and economical points of view, fault current limiting technology for reducing short circuit current is needed. A short circuit cannot be neglected in the power system due to numerous causes. When short circuit occurs in power system, large current will flow in the system which can cause damage to the equipment due to heating effects and electromagnetic forces. Furthermore, during fault, some point in the power system network (depending on the distance of the fault point) will experience voltage sag. This problem may cause to a complete shutdown of healthy plants connected to the network. Power utilities associate that 80-90% of their customers complaining about voltage sags problem.[3] One of the main concerns related with the continuous growth of electricity demand is the corresponding increase in short circuit currents. This problem has been discussed since early 1960s, replacing existing switchgear with others of higher rating is certainly a solution this problem. This solution probably is the best to solve this matter which, solving the increment of the switchgear rating problem as well as providing for future growth. However, this is the most expensive of all the other solution and also consumes a lot of time to replace all existing switchgear which leads to reduction of power system reliability for that period of time. Bus splitting is definitely a cheaper solution to this problem. This entails separation of sources that could possibly feed a fault by the opening of normally closed bus ties, or splitting the existing bus. This effectively reduce the number of sources that can feed a fault, but also reduces the number of sources that supply load current during normal or contingency operating conditions. However, this option may require additional changes in the operational philosophy and control methodology. Furthermore, splitting the bus has implication on network reliability. Other conventional solution to this matter is sequential breaker tripping. Sequential tripping scheme prevent circuit breakers from interrupting excessive fault currents. If a fault is occurred, a breaker tripped first. This reduces the fault current seen by the breaker within the zone of protection at the location of the fault. This breaker can open safely. One of disadvantages of the sequential tripping scheme is that it adds a delay of one breaker operation before final fault clearing. Also, opening the breaker upstream to the fault affects zones that were not originally impacted by the fault. Therefore, a better option is to use FCL[4].

A questionnaire was sent out in 2003 from CIGRE WG A3.16 asking about the typical structures of distribution systems, type of protection used in the networks and the need of limitation of short circuit currents in MV and HV networks. Based on 53 responds from 14 different countries, 74% shows the needs for short circuit current limitation and only 26% state otherwise. Figure 1 shows the pie chart that represented responses from this survey.

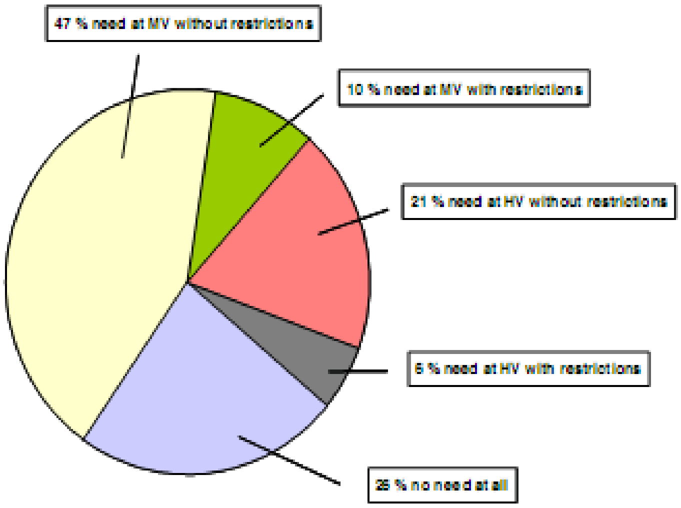


Figure 1– Responses from CIGRE WG A3.16 questionnaire survey

Over the last four decades, different types of FCLs have been under the spotlight in power protection research. In recent years, various types of FCL have been proposed and developed in many countries. Mainly two types of them are discussed most. One is superconductor fault current limiter (SFCL), the other one is solid state fault current limiter (SSFCL). This interest comes not just due to their excellent current limiting characteristics but also due to their positive contribution to the quality of supply. FCLs can be effective in reducing supply outage and mitigate voltage sag on power network.[10]

II. Proposed method

The proposed system is addressing a new and modern optimization tool such as Cat Swarm Optimization (CSO) algorithm. It is generated by observing the behaviors of cats, and composed of two sub-models, i.e., tracing mode and seeking mode, which model upon the behaviors of cats. The modified CSO based BSFC-NSFCL mainly utilizes the magnetic flux cancellation effect to make the limiter behave as a short circuit on the circuit during normal operation. Hence, there is almost no impact on the power system when the limiter is used.

A. Working of Proposed method

A modified bridge switch-type flux-coupling NSFCL (BSFC-NSFCL) is introduced. Since the manufacturing technique of the power reactor has been developed maturely, it has been utilized to construct a high-voltage flux-coupling reactor that can successfully overcome the issue of insufficient interrupting capacity for two CBs in the power system. Consequently, the superconducting flux-coupling reactor in can be replaced by the conventional copper-wound flux-coupling reactor. The magnetic core of the reactor can adapt an air core or iron core with an air gap to avoid magnetic saturation. In addition, abridge switch with a single driver and a simple control strategy is used to replace two anti-parallel RG-IGBTs. The bridge switch only possesses one active switch, and thus it is more reliable than the switch using anti-parallel RB-IGBTs. In addition, only one MOV is required to be installed to restrict the transient overvoltage caused by the secondary coil's inductance. It is worth noting that the proposed FCL is not necessary to connect a CB in series with the primary coil. When a short-circuit fault continuously exists, a feeder CB (FCB) can be used to play the same role in clearing the fault.

The circuit configuration of the proposed BSFC-NSFCL is shown in Fig. 2(a) and its installation placement of the FCL is illustrated in Fig. 2(b).

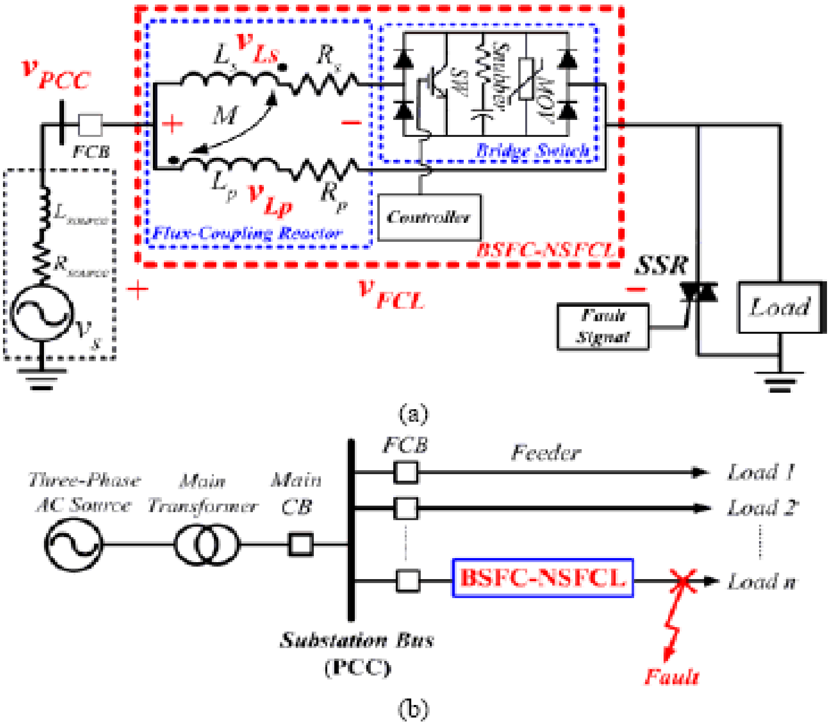


Fig. 2. Circuit structure and placement of BSFC-NSFCL. (a) Circuit configuration of the proposed FCL. proposed FCL. (b) Installation placement of the FCL.

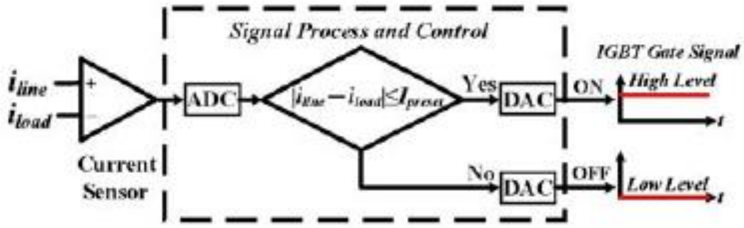


Fig. 3. Control block diagram for the BSFC-NSFCL.

The BSFC-NSFCL is installed in each phase of the three-phase power system and is placed at the outgoing feeder of the substation. The proposed FCL mainly consists two parts: a flux-coupling reactor and a bidirectional bridge switch. The bidirectional bridge switch is installed at the secondary coil of the flux-coupling reactor and consists of a diode bridge rectifier, an IGBT, a RC Snubber and a MOV. It plays an important role in making the two coils couple magnetically during normal operation and in introducing the primary coil during the fault state. The diode bridge rectifier is a passive component and thus possesses higher reliability. Moreover, the bridge switch only has one active switch, and hence it has fewer material costs in comparison with the anti-parallel semiconductor switches. Also, this switch topology is easy to be implemented in the high-voltage power system. The major disadvantage of the bridge switch is that it results in higher power loss than the anti-parallel semiconductor switches. However, its power loss can be negligible in comparison with the power demand of the load. Suppose an air-core flux-coupling reactor is adopted, and the power loss of the BSFC-NSFCL can be calculated as three-phase power system and is placed at the outgoing feeder of the substation. The bidirectional bridge switch is installed at the secondary coil of the flux-coupling reactor and consists of a diode bridge rectifier, an IGBT, a RC Snubber and a MOV. It plays an important role in making the two coils couple magnetically during normal operation and in introducing the primary coil during the fault state. The diode bridge rectifier is a passive component and thus possesses higher reliability. Moreover, the bridge switch only has one active switch, and hence it has fewer material costs in comparison with the anti-parallel semiconductor switches. Also, this switch topology is easy to be implemented in the high-voltage power system. The major disadvantage of the bridge switch is that it results in higher power loss than the anti-parallel semiconductor switches. However, its power loss can be negligible in comparison with the power demand of the load. Suppose an air-core flux-coupling reactor is adopted, and the power loss of the BSFC-NSFCL can be calculated as

$$P_{loss} = R_p i_{Lp,\text{rms}}^2 + R_s i_{Ls,\text{rms}}^2 + \frac{2 i_{Ls,\text{peak}}}{\pi}(V_{sw} + 2V_{DF}), \quad (1)$$

Where *iLp*,rms and *iLs*,rms are the rms values of the flux-coupling reactor's primary and secondary steady-state currents, respectively, *iLs*,peak is the maximum value of the flux-couplingreactor's secondary steady-state current, *RP* and *RS* are the

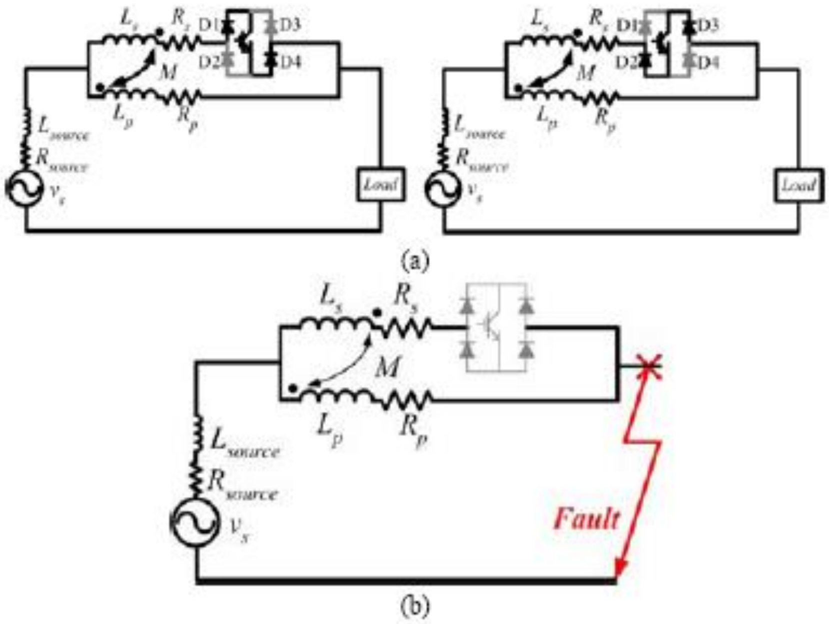


Fig. 4 Circuit diagrams for normal operation and fault state. (a) Steady-state circuits for every half cycle. (b) Fault state.

Resistances of the flux-coupling reactor's primary and secondary coils, respectively, and Vsw and VDF represent the voltage drops across the IGBT and forward-biased diode, respectively. The comparison between the three-phase power losses resulted from the BSFC-NSFCL and load consumption can be expressed as

$$\alpha = \frac{3 \times P_{loss}}{3 \times P_{load}} = \frac{R_p i_{Lp,\text{rms}}^2 + R_s i_{Ls,\text{rms}}^2 + \frac{2 i_{Ls,\text{peak}}}{\pi}(V_{sw} + 2V_{DF})}{i_{line,\text{rms}}^2 \times R_{load}}, \quad (2)$$

Where i line,rms is the rms values of line current, and R_{load} is the load resistance.

The installation purpose for the MOV and RC Snubber is to eliminate the transient overvoltage caused by turning off the IGBT. When a fault event occurs, the secondary current of the flux-coupling reactor needs to be interrupted immediately, and a transient overvoltage may occur across the bridge switch. Since the RC Snubber is connected in parallel between the output terminals of the rectifier, the secondary current can flow through it at the fault inception to avoid damaging the IGBT and diode bridge rectifier caused by a dv/dt phenomenon. After the fault is cleared, the bridge switch subsequently conducts, and the transient overvoltage may also occur across the switch. The MOV is also used to suppress the transient overvoltage resulted from the conduction of the IGBT when the downstream fault is cleared. Besides the main circuit structure, a current detection and control circuit also needs to be installed to detect the fault current and trigger the IGBT. The control strategy of the controller is shown in Fig. 2. During normal operation, the line current i *line* is equal to the load current iload, and thus the IGBT turns on. At the fault inception, once the value of |iline –iload|exceeds the preset value Ipreset, the IGBT turns off immediately.

III. Operation Principle

The operation principle of the BSFC-NSFCL can be divided into two states, depicted as follows.

A. Normal state:

During this state, the line current separately flows through the primary and secondary windings of the flux-coupling reactor. The circuit diagram of this state is demonstrated as Figs. 4(a) and 4(b), respectively. During this state, the IGBT turns on, and the diode strings D1 and D4 and D2 and D3 conduct, alternatively. Therefore, the bridge switch allows the secondary current to flow through the secondary winding of the flux-coupling reactor bi-directionally. Since the primary and secondary coils of the BSFC-NSFCL are wound in an opposite and concentric arrangement, it is magnetically coupled in this state, and the fluxes resulted from the primary and secondary coils counteract each other. Thus, the voltage across the flux-coupling reactor is nearly zero. The turns of the flux-coupling reactor's primary side is less than its secondary side so that it can ensure that less line current flows through the bridge switch. The turn's ratio Np/Ns is 1/n, where Np and Ns are the number of turns in the flux-coupling reactor's primary and secondary coils, respectively. This design purpose is mainly to achieve the current sharing function so that the power loss of the bridge switch can be reduced. Moreover, if the bridge switch fails, the flux-coupling reactor will still remain in the circuit and acts as a reactor. As long as the impedance of the flux-coupling reactor's primary coil is designed to be capable to limit the fault current to the expected value and to make the load voltage maintain an acceptable level, there is almost no reliability issue for installing the BSFC-NSFCL in the distribution power network. During this state, the voltage across the BSFC-NSFCL is small enough to be negligible, so there is almost no influence on the circuit when the BSFC-NSFCL is installed.

B. Fault state

When a fault event occurs at the downstream of the BSFC-NSFCL, the current detection and control circuit detects the fault current and then turns off the bridge switch. The secondary side of the flux-coupling reactor is open-circuited, and the fault current will totally flow through the primary side of the flux-coupling reactor. Since the primary inductance of the flux-coupling reactor can restrain the fault current to the expected fault current value. After the fault is cleared, the BSFC-NSFCL will fast recover to the normal state and be ready for the next short-circuit fault occurrence.

IV Control System

The source current is continually measured and analyzed in this work and the Cat Swarm Optimization is producing the crisp output for the minute change in the source side as well as load side current. The following section represents the concept of Cat Swarm Optimization controller.

A. Natural Process of the Cat Swarm Optimization Algorithm

Despite spending most of their time in resting, cats have high alertness and curiosity about their surroundings and moving objects in their environment. This behavior helps cats in finding preys and hunting them down. Compared to the time dedicated to their resting, they spend too little time on chasing preys to conserve their energy.

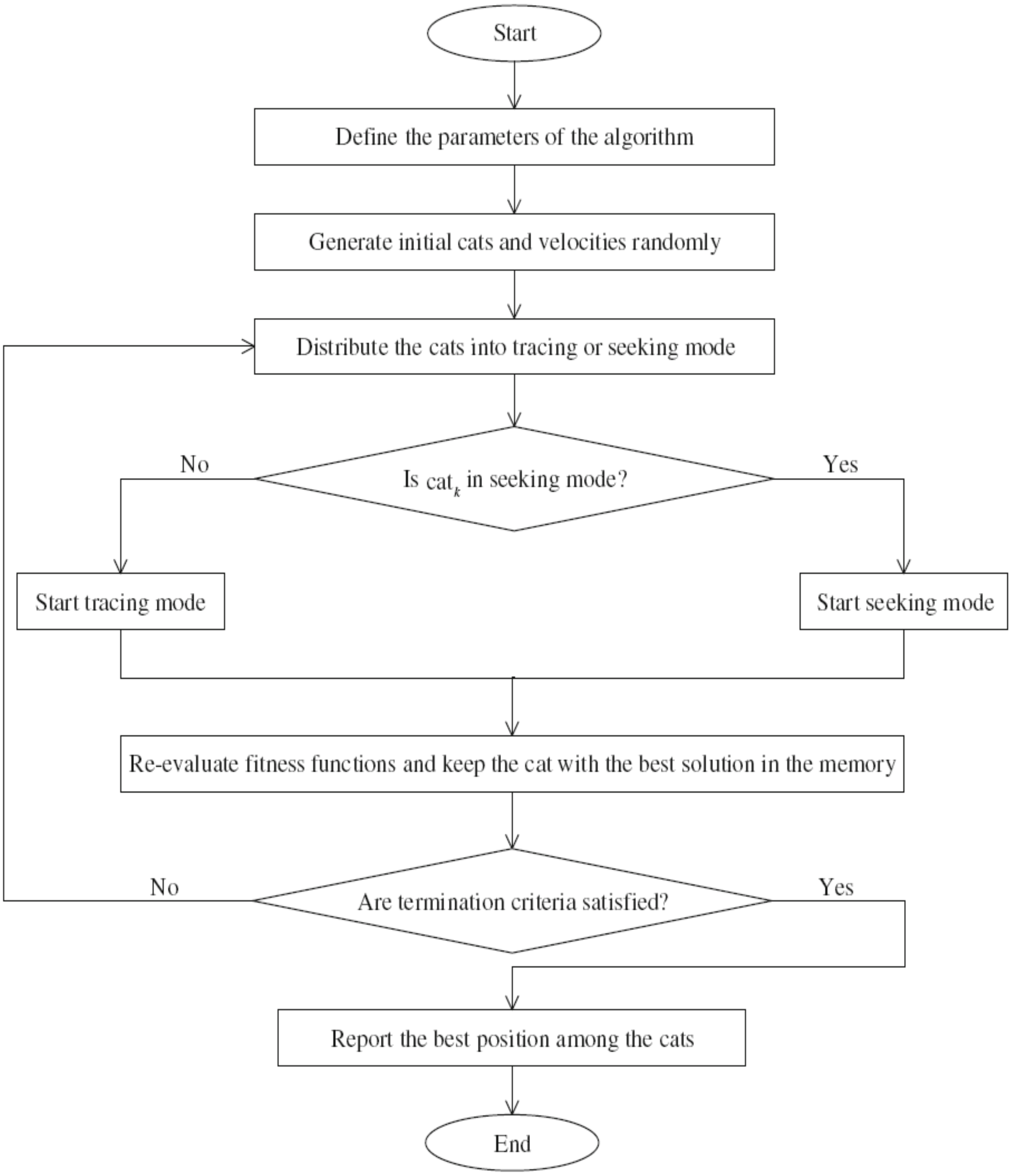
Inspired by this hunting pattern, Chu and Tsai (2007) developed CSO with two modes: "seeking mode" for when cats are resting and "tracing mode" for when they are chasing their prey. In CSO, a population of cats are created and randomly distributed in the M-dimensional solution space, with each cat representing a solution. This population is divided into two subgroups. The cats in the first subgroup are resting and keeping an eye on their surroundings (i.e., seeking mode), while the cats in the second subgroup start moving around and chasing their preys (i.e., tracing mode). The mixture of these two modes helps CSO to move toward the global solution in the M-dimensional solution space. Since the cats spend too little time in the tracing mode, the number of the cats in the tracing subgroup should be small. This number is defined by using the mixture ratio (MR) which has a small value. After sorting the cats into these two modes, new positions and fitness functions will be available, from which the cat with the best solution will be saved in the memory. These steps are repeated until the stopping criteria are satisfied.

B. The computational procedures of CSO

Step 1: Create the initial population of cats and disperse them into the M-dimensional solution space (Xi,d) and randomly assign each cat a velocity in range of the maximum velocity value (ti,d).
Step 2: According to the value of MR, assign each cat a flag to sort them into the seeking or tracing mode process.
Step 3: Evaluate the fitness value of each cat and save the cat with the best fitness function. The position of the best cat (Xbest) represents the best solution so far.
Step 4: Based on their flags, apply the cats into the seeking or tracing mode process as described below.
Step 5: If the termination criteria are satisfied, terminate the process. Otherwise repeat steps 2 through 5.

General algorithm	Cat swarm optimization
Decision variable	Cat's position in each dimension
Solution	Cat's position
Old solution	Old position of cat
New solution	New position of cat
Best solution	Any cat with the best fitness
Fitness function	Distance between cat and prey
Initial solution	Random positions of cats
Selection	–
Process of generating new solution	Seeking and tracing a prey

Table 1 Characteristics of the CSO algorithm



C. Hardware Setup

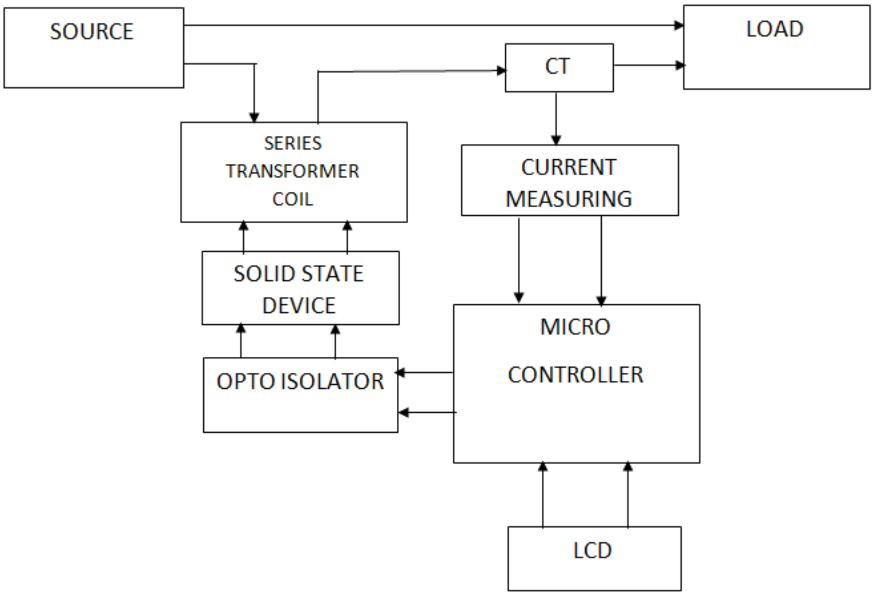


Fig 5. **Hardware block diagram**

The proposed circuit diagram consists of a dual power supply (+5V,-5V). The output voltage goes to all IC's operating voltage. The line current measuring devices CT, the current transformer connect to the series of the load. Current transformer output connects to the Shunt resistor to drop the current and allow the voltage. The voltage signals goes to IC 741 pin 2. This attenuator circuit increases the voltage. The output signals go to microcontroller. Phase current signal go to controller .The microcontroller PIC 16f877A is used. The controller input analog signals convert into digital signal. The controller compares the input value and set value. To increase the input signal the controller output is high. As a same time the LCD display is displaying the current. The controller output signal is go to buffer. The buffer amplifies the signals. This output is connected to the optocoupler. The optocoupler electrically isolate the devices. Optocoupler output is connected to the MOSFET gate. The gate pulse is high, MOSFET is switched ON. Also if, SFCL switch is in ON condition means, if any fault current flows the SFCL MOSFET will be ON and the corresponding fault current will be limited through the inductive load.

V. Results and Discussion

A. Simulation platform

The unique software package used for modeling, simulating, and analyzing the dynamical systems is simulink . It is used to support linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems having different parts are sampled or updated at different rates.

The systems can be simulated using a choice of integration methods, either from the Simulink menus or by entering commands in MATLAB's command window. The menus are particularly convenient for interactive work, while the command-line approach is very useful for running a batch of simulations. The simulation results can be viewed while the simulation is running through scopes and other display blocks. The post processing and visualization of simulation results can be obtained using MATLAB. Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus the many tools in MATLAB and its application toolboxes. The models can be simulated, analyzed, and revised in any environment at any point by integrating MATLAB and Simulink .

The injected 3L-L fault current and voltage are measured with the help V-I measurement block and the corresponding waveforms are shown in the following figure 6

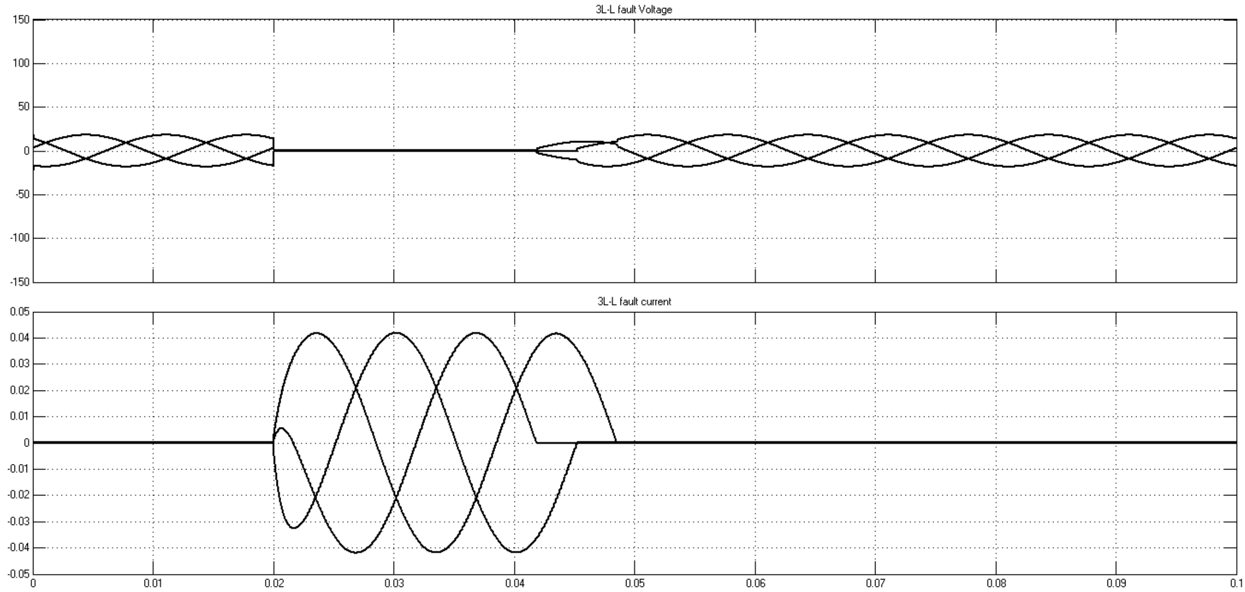


Figure 6 3L-L fault voltage and current

The fault current limitation is analyzed on both load side and source side and with and without BSFC-NSFCL block. The current waveforms in the source side with fault on two cases are with and without BSFC-NSFCL is represents in the following figures 7 and 8 respectively.

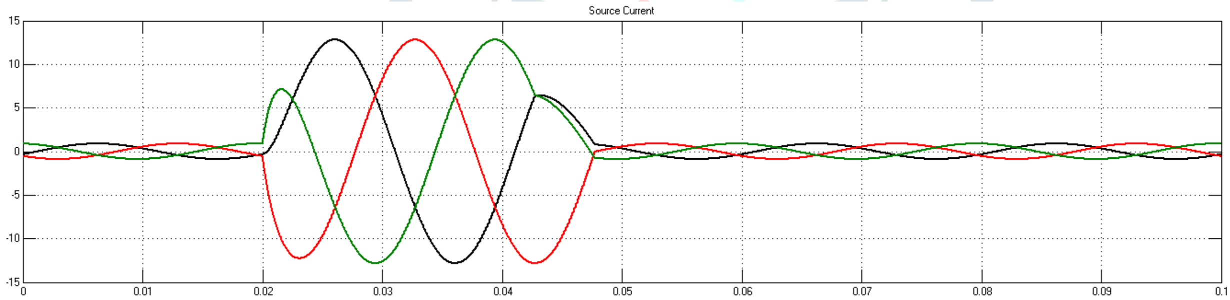


Figure 7 Source side current with Fault &without BSFC-NSFCL

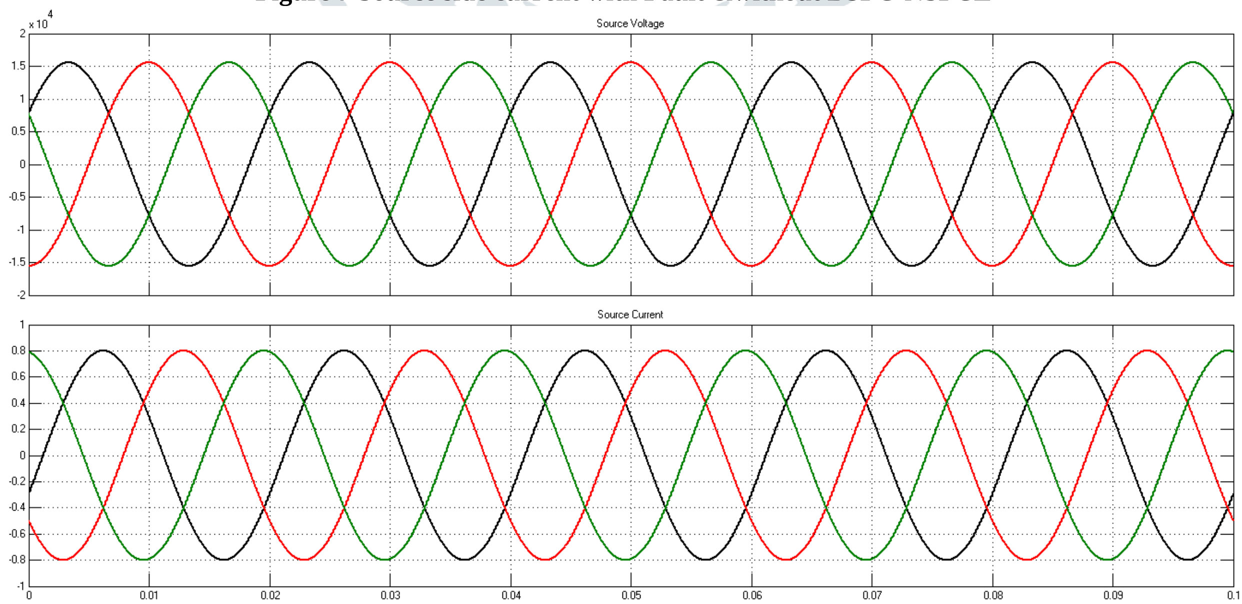


Figure 8 Source side voltage & current with Fault &BSFC-NSFCL block

The above waveforms demonstrates the importance of BSFC-NSFCL on the power system very clearly. The source current and voltage are still stable during the fault occurrence time period [0.002 to 0.004s]. By this way the BSFC-NSFCL supports the source side stability at critical scenarios.

The voltage and current waveforms on the load side with fault on two cases ie. with and without BSFC-NSFCL is represents in the following figures 9 and 10 respectively.

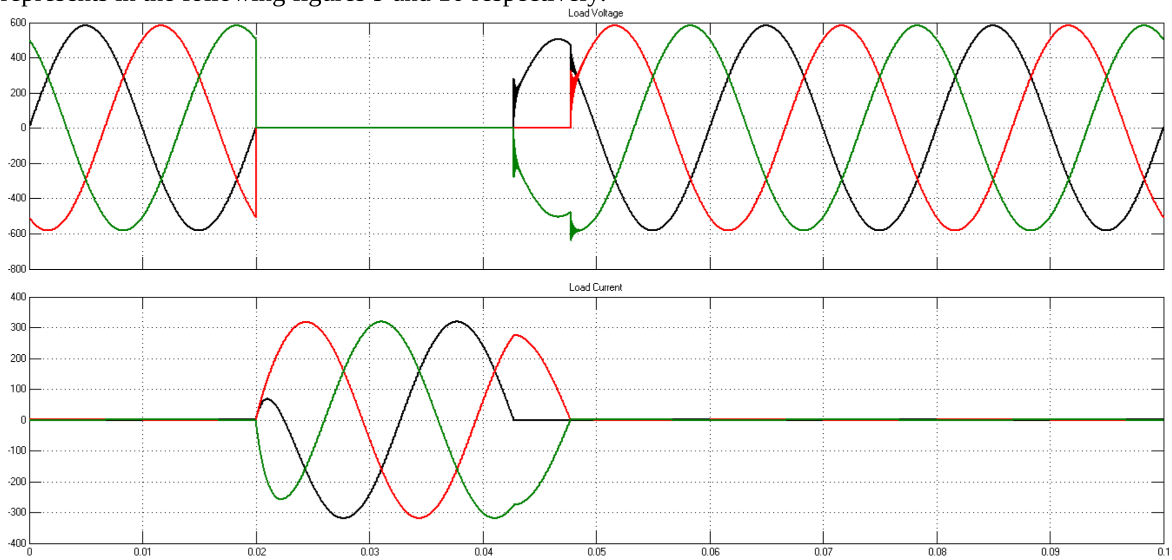


Figure 9 Load Voltage & current with Fault & without BSFC-NSFCL

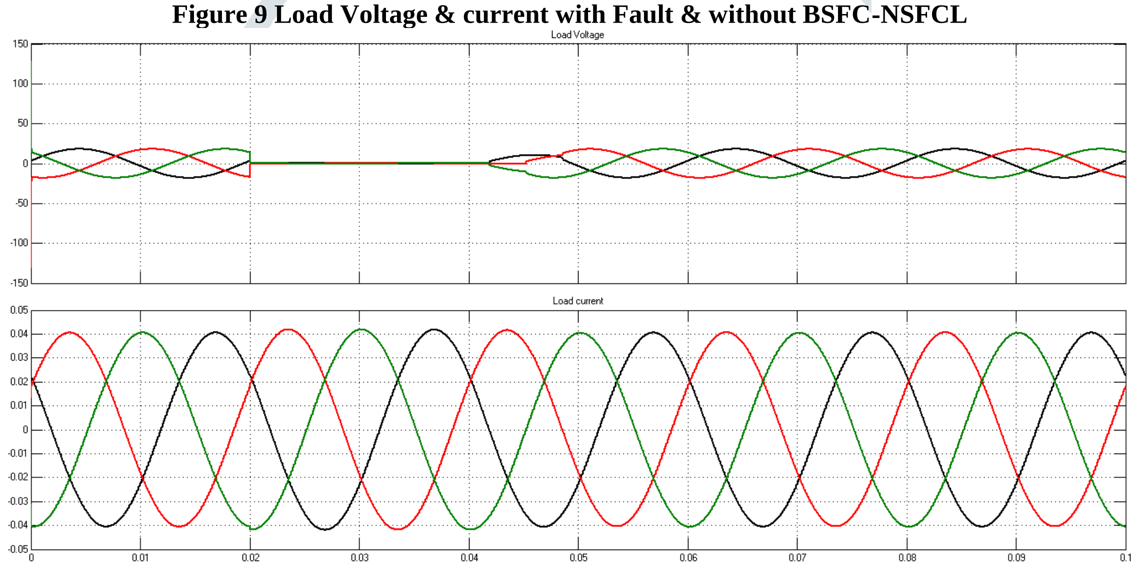


Figure 10 Load voltage & current with Fault &BSFC-NSFCL block

The above waveforms demonstrates the importance of BSFC-NSFCL on the power system very clearly. The source current and voltage are still stable during the fault occurrence time period [0.002 to 0.004s]. By this way the BSFC-NSFCL supports the source side stability at critical scenarios.

VI. Conclusion

In this work, a flux-coupling reactor and a bidirectional bridge switch are combined to perform the functions of steady-state line current sharing and fault current suppression. The proposed system is addressing a new and modern optimization tool such as Cat Swarm Optimization (CSO) algorithm. The two sub models tracing mode and seeking mode are generated by observing the behaviors of cats. The modified CSO based BSFC-NSFCL mainly utilizes the magnetic flux cancellation effect to make the limiter behave as a short circuit on the circuit during normal operation. Hence, there is almost no impact on the power system when the limiter is used. In future implementation of Cat Swarm Optimization based Solid State Fault Current Limiter in Distribution System can be designed.

References

[1] H. Radmanesh, S. H. Fathi, and G. B. Gharehpetian, “Bridge-type solid-state fault current limiter based on AC/DC reactor,” IEEE Trans. Power Del., vol. 31, no. 1, pp. 200–209, Feb. 2016.

[2] S. Kalsi, Applications of High Temperature Superconductors to Electric Power Equipment, New York: Wiley-IEEE Press, 2011, pp. 173–217.

[3] M. Nazari-Heris, H. Nourmohamadi, M. Abapour and M. Sabahi "Multilevel nonsuperconducting fault current limiter: analysis and practical feasibility," IEEE Trans. Power Electorn., vol. 32, no. 8, pp. 6059–6068, Aug. 2017.

[4] M. Jafari, S. B. Naderi, M. TarafdarHagh, M. Abapour, and S. H. Hosseini "Voltage sag compensation of point of common coupling (PCC) using fault current Limiter," IEEE Trans. Power Del., vol. 26, no. 4, pp. 2638–2646, Oct. 2011.

[5] J. F. Moon, S. H. Lim, J. C. Kim, and S. Y. Yun, "Assessment of the impact of SFCL on voltage sags in power distribution system ," IEEE Trans. Appl. Super conduct., vol. 21, no. 3, pp. 2161–2164, Jun. 2011.

[6] S. Quaia and F. Tosato, "Reducing voltage sags through fault current limitation," IEEE Trans. Power Del., vol. 16, no. 1, pp. 12–17, Jan. 2001.

[7] S. A. Yin, R. F. Chang, and C. N. Lu, "Reliability worth assessment of high-tech industry," IEEE Trans. Power Syst., vol. 18, no. 1, pp. 359–365, Feb. 2003.

[8] S. Chen, P. Li, R. Ball, J. -F. de Palma, and B. Lehman, "Analysis of a switched impedance transformer-type nonsuperconducting fault current limiter," IEEE Trans. Power Electron., vol. 30, no. 4, pp. 1925-1936, Apr. 2015.

[9] M. Abapour and M. T. Hagh, "Nonsuperconducting fault current limiter with controlling the magnitudes of fault currents," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 613–619, Mar. 2009.

[10] A. Abramovitz and K. M. Smedley, "Survey of solid state fault current limiters," IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2770–2782, Jun. 2012.