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Comparative Analysis of PSO and Proposed Hybrid (CSA-SSA) Algorithm for Optimal DG Location and FCL Sizing

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Abstract:
Power system is the complex network in nature due to the integration of several devices such as circuit breakers, fuses, relays and power electronic equipment's. Protection of these devices is a highly exacting task in the modern power system. The incorporation of DG has many advantages besides this it causes grid disturbances. DG integration with the existing distribution system increases the short circuit current levels. DG is producing fault currents which exceeds the breaking capacity of C.B and fuses. Fault current limiter (FCL) is most adapted technique to limit the abnormal electric current levels to an acceptable level. In this paper, Controlled Impedance type of FCL (CI-FCL) is used and it is tested on IEEE standard 33 and 69 distribution bus systems. The obtained Hybrid (CSA-SSA) results are verified with PSO technique.

Keywords*: Distributed Generation, Hybrid CSA-SSA Algorithm, Controlled Impedance Fault Current Limiter.*

Introduction:

Due to the increasing pursuit of Electricity, environmental concerns and reliability it is important to change our coal rich energy resource to a grid which produce clean and green energy. Dispersed Generation (DG) is the latest trend in power system to meet the peak demand management. The IEEE [1] defines the connection of small generating units connected near the customer loads or distribution substations is called as Distributed Energy Resources (DER). Incorporation of DG to the distribution network increases energy efficiency and reliability. But, however it has some negative impact on the system which increases the value of abnormal electric current which is not limited by our traditional protective devices such as air core reactors, C.Bs, relays, fuses and it causes various protection challenges [2]-[8]. One of the most adapted technique to reduce this problem is to install fault current limiter (FCL) at optimal places [9]-[13].FCL can be classified in to two types mainly passive and active. Passive FCL are current limiting reactors which remains unchanged in the circuit during normal and abnormal electric current conditions which causes excessive voltage drop. Whereas active FCL introduces small impedance/zero impedance during usual condition and high impedance during abnormal electric current flows in the circuit.

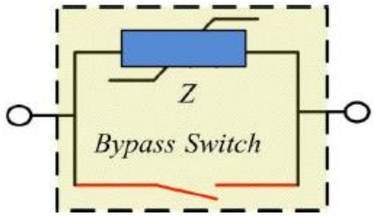

Fig.1.Active Type of FCL.

An ideal fault current limiter should be designed in such a way

- It should have zero impedance in the system during usual condition.
- Increases its impedance during abnormal electric current flows in the circuit.

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- Fault should be cleared within the first cycle.
- It should not affect any other protective devices.
- It should be small size and cost effective.

Related work

[14] Ramzan Bayindir Et.al. Presents the need of DG technology of a micro grid. It also includes various power electronic interfaces and the interconnection of multiple micro grid and provides insight in to the possible evolvement of future grids. [15] Nirav Chauhan Et.al. Discussed the impacts of distributed generation on short-circuit current, power quality issues and coordination problem.

[16] A.Elmitwally Et.al discusses about the problems of integration of DG and uses different types of FCLs to study over current relay coordination issues. Multiobjective PSO is adopted to setup the coordination between the main relay and backup relay.[11] M.A.Salma Et.al proposed a new FCL Thyristor controlled impedance which gives several economic benefits and also effectively reduces the short-circuit current level [17] H.H.Zeineldin Et.al proposed optimal sizing of TCI-FCL of both inductive and capacitive type to decrease the short-circuit level under multiple configurations. PSO is adopted for FCL sizing both in islanded and grid connected mode. [12]- [13] In this the authors consider DG in Grid-connected operation. In [13] the cost function is utilized to determine the cost of the various protective devices used in the distribution network and includes penalty value to assure the fault current level. [18] Navid bayati Et.al proposed the optimal placing and sizing of FCL by maintaining the relay coordination before and after connecting the DG by adopting the hybrid genetic algorithm. In [19] Cuckoo optimization and PSO algorithm was adopted to coordinate overcurrent relays of micro grid .It was tested both for grid connected mode and island mode using resistive and inductive FCLs. In [20] A.S.Hoshyarzadeh Genetic algorithm (GA) is implemented for optimal placement of DG and FCL sizing.GA and other optimization algorithms have been used for various engineering problems .In this paper Hybrid CSA-SSA [23]-[24] algorithm is proposed for optimal DG location and Controlled impedance (CI) FCL sizing. Here the objective function is to minimize the network losses and also to reduce the error between impedance matrices

I. Impacts of DG on Power System

As per literature review many researchers found that there are some major issues when Dispersed Generation is incorporated to the power system.

A. *Type of DG connected:*

Generally, Synchronous generator contributes high fault currents when compared to induction generators. The contribution of fault currents is equal to induction generator during first few cycles, after few cycles the synchronous generator contributes more fault currents. It passes through different states

- Sub transient state (0-50ms)
- Transient state (50ms-1s)
- Steady state (>1s)

B. *Impact on Voltage Regulation:*

Voltage profile in radial distribution systems can be improved by using shunt capacitors and LTC along the line. Impact of Dispersed Generation on voltage regulation can be positive (or) negative depends on DG location and DG characteristics.

C. *Impact on Harmonics:*

Power electronic equipment such as inverters, converters and synchronous generators produces harmonics and causes extra heating. The Total harmonic distortion (THD) limits for utility system is 5 % and 3% for individual harmonic.

D. *Impact on Short-Circuit levels*

The incorporation of Dispersed Generation increases the fault current levels when compared to usual condition. The effect of fault current from one DG is not large, multiple DGs increases the fault current level which causes miscoordination between protective devices like fuses, Circuit breakers, Relays.

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E. Impact on Protection system

The effect of Dispersed Generation incorporation on protection system causes the following problems

- Sympathetic tripping
- Protection Blinding.
- Unintentional Islanding
- Mis-Coordination problems
- Nonsynchronous reclosing.

II. PROBLEM FORMULATION

From the above discussion, it is clear that the incorporation of DG has impact on the fault currents. The protective devices installed such as C.B's, fuses, relays can't withstand its capability to reduce the fault current. Hence the problem is formulated to optimal place DG and CI-FCL is used to limit the short-circuit current to acceptable level.

The objective of Hybrid (CSA-SSA) can be defined as

$$F(x, y) = [\sum_{i=1}^{n} P_i \text{ loss} + \sum_{i=1}^{n}\sum_{j=1}^{n} [Z_{absolute\ i,j} - Z_{modified\ ij}] \quad (1)$$

For loss reduction, DG location should be properly placed. The exact loss formula [25] used for calculation of real power loss is expressed as

$$P_{loss} = \sum_{i=1}^{n}\sum_{i=1}^{n} \alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j) \quad (2)$$

Where, $r_{ij} + x_{ij} = Z_{ij}$

$\alpha_{ij} = rij/vivj \cos(\delta i - \delta j)$ (3)

$\beta_{ij} = rij/vivj \sin(\delta i - \delta j)$ (4)

Z bus is an impedance matrix

Pi, Qi = Real and Reactive power at node i

Pj, Qj = Real and Reactive power at node j

$Pi = (P_{DGi} - P_{Di})$ (5)

$Qi = (Q_{DGi} - Q_{Di})$ (6)

P_{DGi}, Q_{DGi} - Real and reactive power at DG placed at node i

P_{Di}, Q_{Di} - Real and reactive power demand at node i

$$PDGi = \alpha_{ij} (P_{Di} + a Q_{Di}) - Xi - aYi / a^2 \alpha_{ii} + \alpha_{ii} \quad (7)$$

$$a = \pm \tan(\cos\text{-}1(PF_{DG}))$$

+ve sign injects reactive power, -ve sign Consumes reactive power

Voltage constraints,

$Vimin \le Vi \le Vmax, 0.9p.u \le Vi \le 1.p.u$ (8)

Optimal location of DG

$2 \le m \le$ total no.of. buses,m€Z (9)

The boundaries for IEEE 33 and 69 standard distribution bus systems are given in Table 1.Here, in this paper consider two configurations. Z*absoulte* is the impedance matrix in normal operation without DG connected. Z*modified* is the impedance matrix in DG connected mode. Here the problem is formulated to reduce the difference between the impedance matrices. In order to reduce the error, DG is placed optimally and CI-FCL sizing is reduced. This objective is tested on both IEEE 33 and 69 standard distribution bus system.

$Z_{absolute}$: Grid connected without DG connected.

$Z_{modified}$: Grid connected with DG connected.

For both IEEE 33 and 69 bus systems the total demand is about 4.5MW is considered. It can be provided by three (1.5MW) DGs (or) 2 MW DGs $Z_{absolute}$ is impedance matrix in normal operation .$Z_{modified}$ gives the impedance matrix when DG is connected. This matrix includes DGs impedance, location of DG, Source impedance placed at the utility. Source impedance is connected to bus 1 to maintain fault currents, whereas CI-FCL is connected in series with DG. It gives zero impedance during usual condition and gives high impedance during abnormal electric current condition. Thus this high impedance value limits the short circuit current level to acceptable value. CI-

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FCL can be the combination of resistive, Inductive or combination of both.

$Z_{modified}$ =F (CI_k ,l_k, P_k, TCI_s) $\forall k=1:n$ (10)

CI_k – Controlled impedance in series with DG number k
l_k – location of DG number
P_k – power generated by DG number k
CI_s – Controlled source impedance connected at the utility.

$ZCI_k=R_k+jX_k \forall k=1:n$ (11)
$ZCI_s=R_s+jX_s$ (12)

R_k and X_k are the resistive and reactive component of CI-DG_k
R_S and X_S resistive and reactive parts of CI source impedance.
The i^{th} diagonal element Z_{ii} represents the thevenin's impedance from this bus.the fault current can be calculated as

If bus i=1/Z_{ii} (13)

In this way calculate fault current at bus i, assuming the voltages at all the buses as 1 p.u, V=1 p.u.
Z_{ij} is the fault current between bus i and bus j, the fitness function is difference between two impedance matrices, it can be expressed as follows

$$\sum_{i=1}^{n} \sum_{j=1}^{n} [Z_{absolute\ i,j} - Z_{modified\ i,j}] \quad (14)$$

The fault currents can be maintained by reducing the error between two matrices and it is given as objective function in Eq (14).The problem is non-linear and integer constrained. According to the no .of power system buses, bus numbers in which DG can be installed are integer variables and limited.

No.of. Variables required for hybrid CSA-SSA = nDGs + nFCLs (15)
The limitations of CI-FCL is given below

$0\leq R_k \leq Rmax_K$ (16)
$Xmin_k \leq X_k \leq Xmax_k$ (17)
$0 \leq Rs \leq Rmax_s$ (18)
$Xmin_s \leq Xs \leq Xmax_s$ (19)

III. PROPOSED HYBRID CSA-SSA ALGORITHM

Optimization problems can be linear and non-linear. Most of the power system problems are non-linear it is solved by Meta heuristic algorithms such as evolutionary [21] and swarm intelligence [22].Hybrid CSA-SSA algorithm is proposed to solve the non-linear, integer constrained problem based on swarm intelligence and population. Crow search algorithm (CSA) is adopted to diminish the losses in the system and to find optimal DG location. Salp Swarm Algorithm (SSA) is utilized to minimize the error between impedance matrices and to reduce the CI-FCL size.

Optimal DG location

Crow search algorithm is one such meta-heuristic algorithm[23]Crows or flock of crows(Corvids) are the intelligent birds they move for food to different places and hide the food at different places in order to protect from being purloined. They remember the hiding places up to several months and can redeem the food when it is needed. Assume a d-dimensional search space, the no of corvids is T.

The hiding place of Crow 'S' at a time iter is

$X^{S,iter} = (1,2,3,4\ldots\ldots T)$
Where $X^{S.iter}=[X_1^{S,iter}, X_2^{S,iter} \text{--------} X_d^{S,iter}]$
(20)
Itermax=max.no.of iterations

Assume Crow 'S' search for best food source and hide the food, memorize the hiding place $m^{S,iter}$. Now let us assume that Crow 'T' wants to sojourn the reserve place $m^{T,iter}$, at this iteration crow 'S' decides to follow crow 'T' in order to find the reserve place of crow 'T', two states may happen.

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STATE 1: Crow 'S' reaches its reserve place unknowingly that crow 'T' is following. The new position of crow 'S' is obtained as follows:

$$X^{S,\, iter+1} = X^{S,iter} + rs*fl^{\,S,iter}(m^{T,\,iter} - X^{S,iter}) \qquad (21)$$

r_s -Random variable with uniform distribution between 0 to 1.
$fl^{\,S,iter}$ –Flight length of crow S at iteration iter.
STATE 2: Crow T will go to another place by fooling crow S from being pilfered .New position in search space
Two states 1 and 2 can be expressed as follows

$$X^{S,\, iter+1} = \begin{cases} X^{S,iter} + rs*fl^{\,S,iter}(m^{T,\,iter} - X^{S,iter}) & r_s \geq AP^{T,iter} \\ \text{A random position} & \text{otherwise} \end{cases} \qquad (22)$$

r_s - Random variable, $AP^{T,iter}$ - Awareness probability of crow T at iteration iter.

Optimal FCL-Sizing

Salp swarm algorithm [24] is the intelligence behaviour of swarm's.Salps belong to the family of salphide and have translucent cylinder body. They forage for their food in deep oceans. They form as salp chains while foraging for the food and water is forced through the body as tension to move forward .these are more similar to jelly fish. Salps are divided in to two groups while searching the food leader and the follower group.
Consider N-dimensional search space,
N-is the no.of. Search agents
A-is the two dimensional matrix where salps are stored
F- Best food source in search space = Best Optimal FCL sizing.
The position of leader is given by Eq (23)

$$A_j^1 = \begin{cases} F_j + c_1((ub_j - lb_j)c_2 + lb_j) & c_3 \geq 0 \\ F_j + c_1((ub_j - lb_j)c_2 + lb_j) & c_3 \leq 0 \end{cases} \qquad (23)$$

A_j^1-Position of first salp in jth dimension
F_j- Food source in j^{th} dimension
ub_j- upper boundary
lb_j - lower boundary
c_2, c_3-random variables in the interval [0, 1]
c_1- It balances the intensification and diversification, it is defined as follows

$$c_1 = 2e\text{-}(4t/t_{max})^2 \qquad (24)$$

t- Current iteration
t_{max}- Max no.of iterations.
The position of follower Salp in j^{th} dimension is given as

$$A_j^1 = 1/2(A_j^i + A_j^{i-1}) \qquad (25)$$

$i \geq 2$, A_j^1-shows position of i^{th} follower salp in j^{th} dimension

IV. SIMULATION

The proposed Hybrid CSA-SSA is applied on an IEEE 33 and 69 bus systems. First CSA is implemented to find optimal location of DGs and FCL sizing is obtained by SSA algorithm. The source impedance is connected to bus 1 at PCC to protect the devices.

IEEE 33 bus system

Fig.2 shows the single line diagram of IEEE 33 bus system. Hybrid CSA-SSA is implemented for both 3 DG and 2 DG operations. In 3 DG operation three 1.5MW DGs are connected to buses 2,8,26 and for 2 DG operation 2 MW DGs are connected to buses 2 and 8.The buses which are connected near to the substations contributes more fault current when compared to buses away from the substation. The total demand of real and reactive power loads is p= 3715Kw ,Q=2300KVar.Fig.3 shows the comparison of fault currents in normal mode and DG-connected mode.CI-FCL is placed in series with DG at these buses to reduce the amount of fault current to acceptable value.Fig.4 shows the comparison of fault currents when CI-FCL is placed.

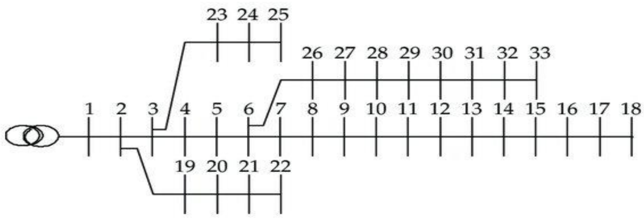

Fig.2.Single line diagram of IEEE 33 bus system

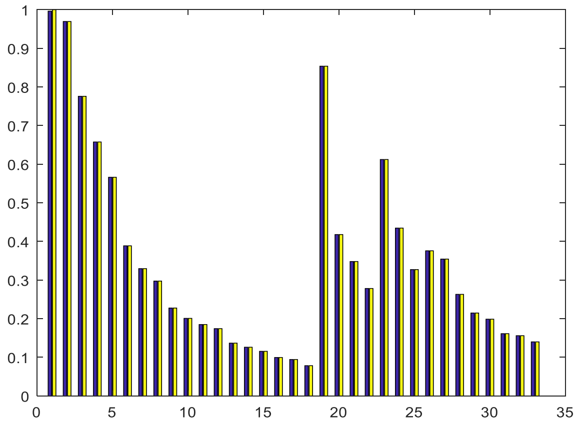

Fig.3.Comparision of Fault current in normal mode-DG connected mode.

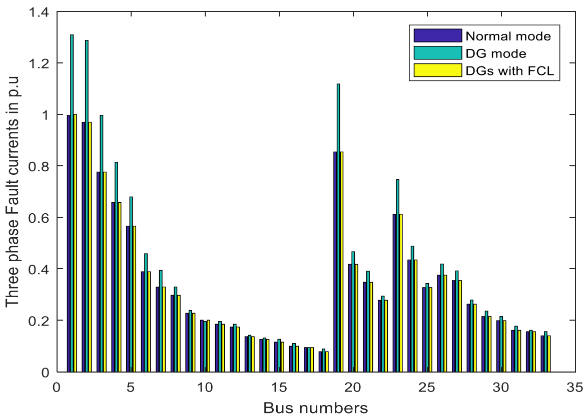

Fig.4.comparison of Fault currents with DGs and FCL

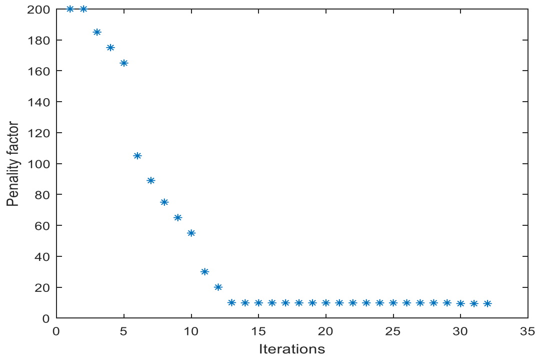

Fig.5.Convergence Diagram of IEEE 33 Bus system

IEEE 69 bus system:

Fig.6 shows the single line diagram of IEEE 69 bus system. Hybrid CSA-SSA is implemented for both 3 DG and 2DG operations.in 3 DG operation three 1.5 MW DGs are connected at buses 12, 31, 46 whereas, in 2 DG operation 2MW DGs are connected at buses 24and 26.the total real and reactive power of this radial distribution system is p=3, 8091Kw, Q=2,694.1KVAr.Fig.7 shows the comparison of fault currents in normal and DG connected mode. The buses which are connected to the substations draws large fault currents when compared to the buses away from the substation. CI-FCL is placed in series with DGs at these buses offers high impedance, reduce the fault currents to acceptable value and protect the devices from coordination failure. Fig.8 shows the comparison of fault currents when CI-FCL is placed.

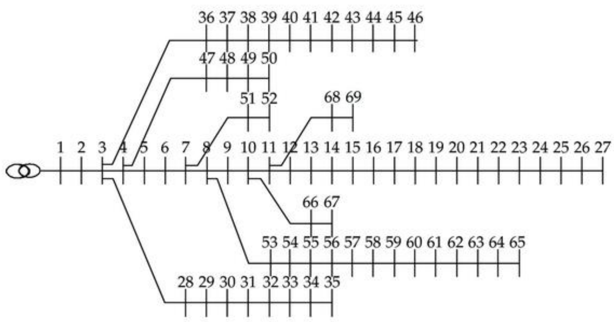

Fig.6.Single line diagram of IEEE 69 Bus system.

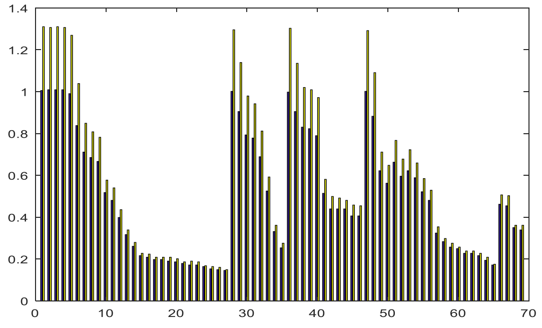

Fig.7.Comparision of fault currents in normal mode and DG connected mode

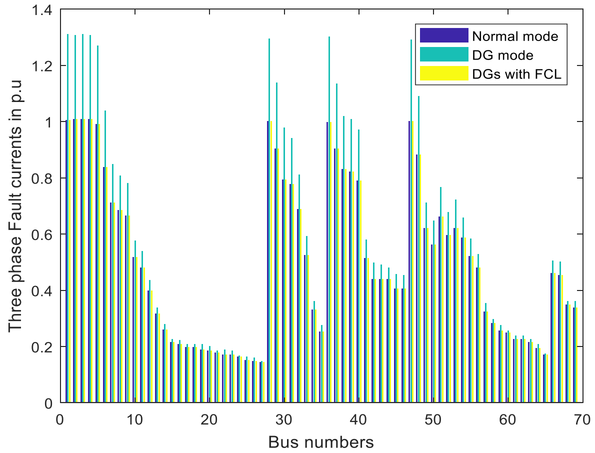

Fig.8.Comparision of fault currents with DGs and FCL

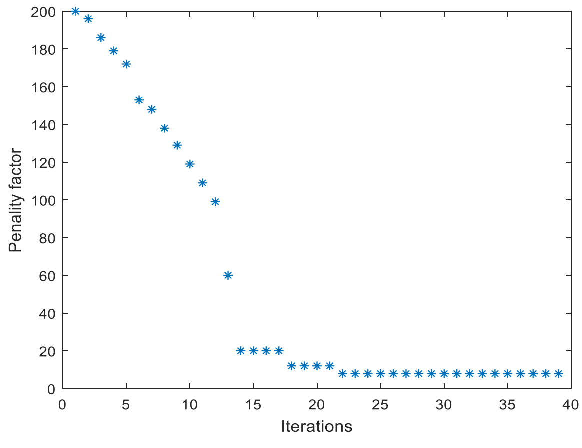

Fig.9.Convergence diagram of IEEE 69 bus system

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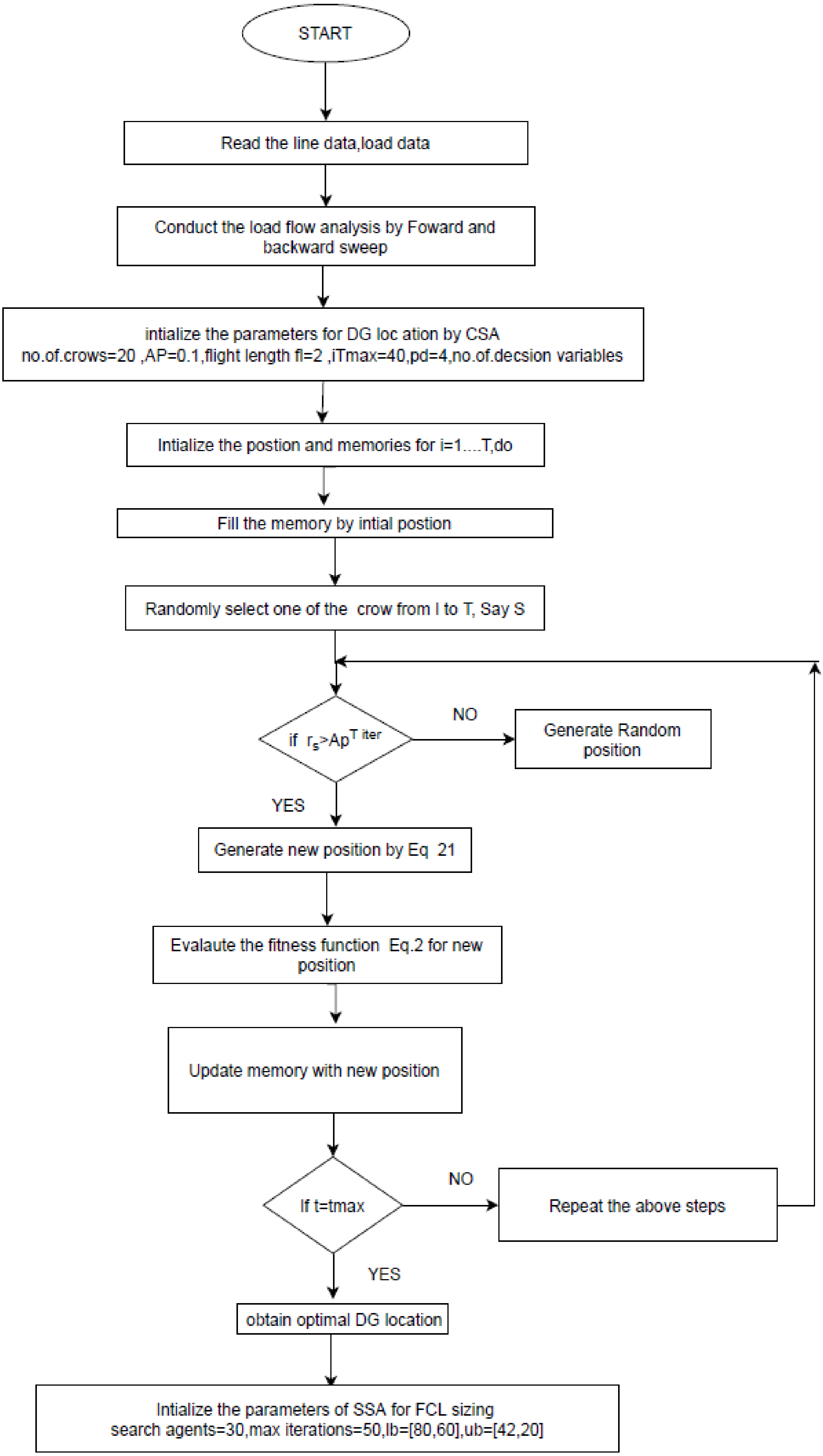
Table.1.Optimization variables for Hybrid CSA-SSA in 33 and 69 bus systems

33 bus system		
variable	Minimum	maximum
X_k & X_s	-10	10
R_k & R_s	0	10
m	2	33
69 bus sytem		
X_k & X_s	-10	10
R_k & R_s	0	10
m	2	69


START
Read the line data,load data
Conduct the load flow analysis by Foward and backward sweep
intialize the parameters for DG loc ation by CSA
no.of.crows=20 ,AP=0.1,flight length fl=2 ,iTmax=40,pd=4,no.of.decsion variables
Intialize the postion and memories for i=1....T,do
Fill the memory by intial postion
Randomly select one of the crow from I to T, Say S
if r_s>$Ap^{T\ iter}$
NO
Generate Random position
YES
Generate new position by Eq 21
Evalaute the fitness function Eq.2 for new position
Update memory with new position
If t=tmax
NO
Repeat the above steps
YES
obtain optimal DG location
Intialize the parameters of SSA for FCL sizing
search agents=30,max iterations=50,lb=[80,60],ub=[42,20]

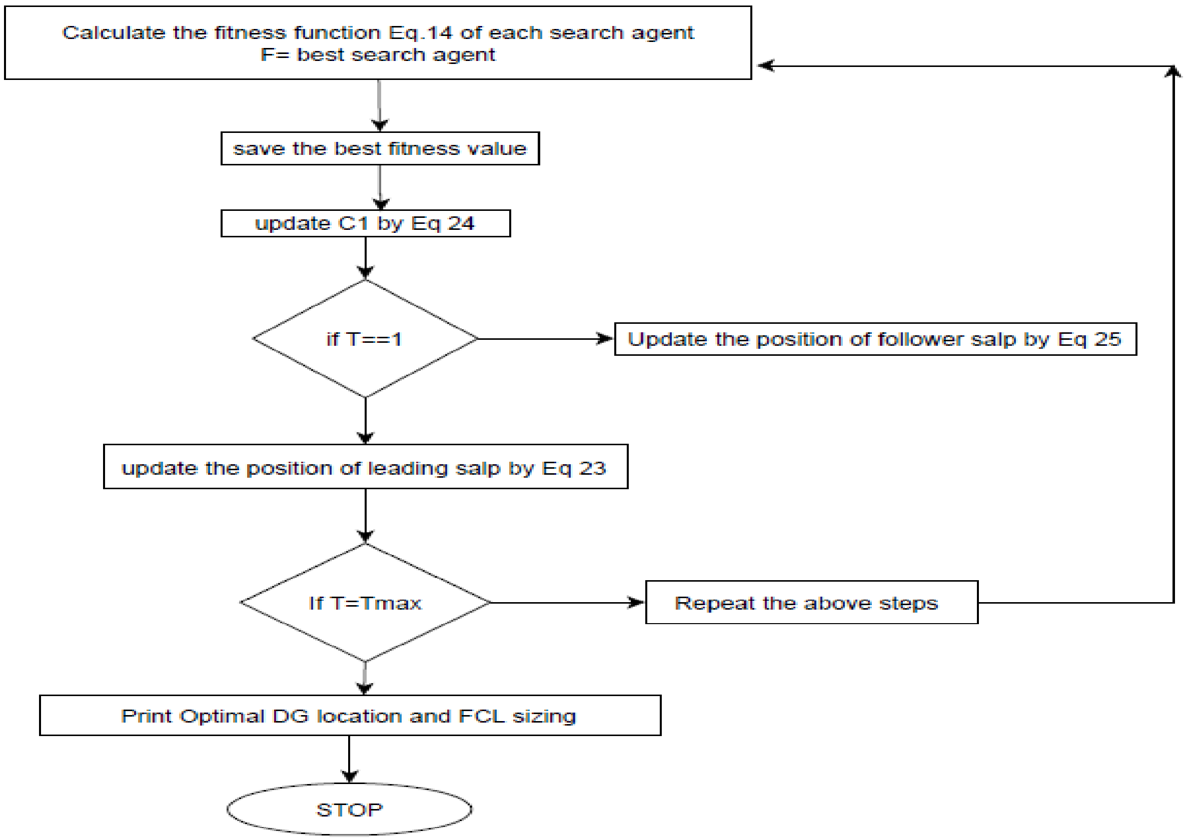


Fig.10.Flow chart of Hybrid CSA-SSA.

Table.2.Simulation data

33 bus and 69 bus source and DG system data	
Utility data	MVA_{sc}=100MVA,X/R=6
DG transformer reactance	$X^{+}=X^{-}=5\%$ Y-grounded
DG reactance	$X^{+}=X^{-}=9.67\%$
Base KV	12.47
Base MVA	100

Table.3.Hybrid CSA-SSA parameters

CSA parameters	SSA parameters
Flock size=20	Search agents=30
Ap=0.1,fl=2	Lb=80,60
Pd=4,no.of.decision variables	Ub=42,20
Max.iterations=40	Max.iterations=50

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Table.4.Simulation results of PSO and Hybrid CSA-SSA for IEEE 33 bus system

Table.4.Simulation results of PSO and Hybrid CSA-SSA for IEEE 33 bus system PSO results for 3 DG					Hybrid CSA-SSA results for 3 DG				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (1.5MW)	2	1.8464+1.994j	0.11566 +0.36305i	9.9140	DG1 (1.5MW)	2	1.67842+1.7829J	1.0052	9.3854
DG2 (1.5MW)	3	6.3021+4.2043j			DG2 (1.5MW)	8	5.7830+4.342j		
DG3 (1.5MW)	19	3.89+2.35j			DG3 (1.5MW)	26	0.0180+2.68601j		
PSO results for 2 DG operation					Hybrid CSA-SSA results for 2 DG operation				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (2MW)	3	9.9882+4.2141j	0.012514 +0.21371i	9.7	DG1 (2MW)	2	1.6752+3.7827j	0.0102 +0.1921j	6.49824
DG2 (2MW)	19	6.0836+6.3737j			DG2 (2MW)	8	1.4540+4.1204j		

Table.5.Simulation results of PSO and Hybrid CSA-SSA for IEEE 69 bus system

PSO results for 3 DG					Hybrid CSA -SSA results for 3 DG				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (1.5MW)	4	4.0267+0.29311j	0.01046 +0.30675i	1.0615	DG1 (1.5MW)	12	3.7987+0.1263j	0.01+0.343	7.803832
DG2	28	2.2563+2.0257j			DG2	31	2.0890+1.623j		

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(1.5MW)					(1.5MW)				
DG3 (1.5MW)	36	3.3053+6.2336j			DG3 (1.5MW)	46	2.9734+4.825j		
PSO results for 2 DG operation					Hybrid CSA-SSA results for 2 DG operation				
DG Number	Location	FCL size	FCL source	Best Fitness	DG Number	Location	FCL size	FCL source	Best Fitness
DG1 (2MW)	2	1.8318+4.5763j	0.029363 +0.19119i	5.4484	DG1 (2MW)	24	1.5623+2.036j	01.21043	1.013832
DG2 (2MW)	5	2.7356+5.1776j			DG2 (2MW)	46	2.2376+5.0103		

CONCLUSION

In this proposed system, an automatic water sprinkling robot which automatically sprinkles the water all over the field without the human intervention is developed. This proposed system is used for both gardening and agricultural purposes. The main concept of this system is to reduce the water usage in fields and gardens. By using this system, man power is reduced and it is also economical for the farmers in our country. This system is used where to reduce the manpower and save the money.

Future work may include some additional features like fixing the moisture sensors in the several places according to the gardening area. It senses the soil moisture content and sends the message to the controller. After that robot moves near the plant and sprinkle the water to that plant and moisture is still sensing by the sensor. This movement of vehicle is done using IoT and wireless sensor networks technology. When the moisture reaches 100%, the controller receives the message and sends back the robot to its original position. This prevents the repeated watering of the same plants and this will be the main advantage.

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