ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 3, March 2016

Series Connected FACTS controllers with Cat Swarm Intelligence for Voltage Stability in Wind Power Networks

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ABSTRACT: Artificial Intelligence has been a medium to test, analyze and elucidate various problems arising in engineering. Electrical engineering applications also find a necessity in applying artificial intelligence to their problems. This technical paper focuses on cat swarm intelligence application for voltage stability problems arising in wind power generation integrated networks. We focus on finding optimal location and size of conventional series flexible alternating current transmission systems to address voltage stability.

KEYWORDS: Cat Swarm Optimization, SSSC, TCSC, Voltage Stability.

I. INTRODUCTION

Swarm intelligence is based on the behavior of self-organized systems coming in natural or artificial form. Swarm intelligence is conceptualized as one of the parts in artificial intelligence. The term swarm intelligence first originated from the ideas of Gerardo Beni in 1989, in the context of cellular robotic systems [1]. Swarm intelligence applications constitute typically of a population of simple agents. These agents interact locally with one another and with their environment. Often, the inspiration comes from nature, to be specific, biological systems. Very simple rules are formulated and followed by the agents. There is no centralized control structure that dictates the behavior of individual agents. Interactions among the agents lead to the emergence of intelligent global behavior which is unknown to the individual agents. Examples of natural swarm intelligence include ants in colonies, flocking of birds, herding in animals, individual animal, bird and beast behavior, bacterial growth, fish schooling and microbial intelligence to mention a few.

It has been a decade that cat swarm optimization is proposed [2]. Since then, it has been applied in many different fields of engineering and science by many researchers. Cat Swarm Optimization imitates the behavior of cats. Cat Swarm Optimization is generated by observing the behaviors of cats in tracing mode and seeking mode. Voltage collapse is a process in which the voltage falls to an unacceptably low value as a result of an avalanche of events accompanying voltage instability [3]. Once associated with weak systems and long lines, voltage problems are now a concern in highly developed networks as a result of heavier loading. These also include renewable energy integrated power networks.

II. LITERATURE REVIEW

In [2], Shu-Chuan Chu has demonstrated the behavior of cat swarm intelligence in comparison to particle swarm intelligence and concluded on giving a vote to the former. In [6], authors presented a novel cat swarm intelligence approach for unconstrained optimization problems in computer science. In [9], optimal location of unified power flow controller in an interconnected power system under N-1 contingency was addressed for voltage stability issues in electrical engineering.

III. OBJECTIVE FUNCTION

Voltage instability arising in a wind power network during line outage contingency is addressed using cat swarm intelligence. Optimal location and size of the series flexible alternating current transmission systems are determined using

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ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

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cat swarm optimization. An improvement in voltage magnitude profile and maximum loadability limit is targeted. The objective function for achieving the above is defined as follows.

$$A = \{A_1, A_2\} \qquad (1)$$

The functions A_1 and A_2 are defined as:

The prime part of the objective function concerns the voltage level. It is favourable to have bus voltages at 1 per unit according to equation (2).

$$A_1 = A_V = [\sum_{i=1}^{n_b} (V_i)^2]^{1/2} \qquad (2)$$

The second issue in our problem is determining inverse of maximum loadability, given as follows.

$$A_2 = A_{SM} = 1/\lambda_{Critical} \qquad (3)$$

The functions A_1 and A_2 are defined and used in optimization process.

$$A = \mu_1 A_1 + \mu_2 A_2 \qquad (4)$$

Therefore, the objective function is given by (5).

$$A = \mu_1 A_V + \mu_2 A_{SM} \qquad (5)$$

IV. CAT SWARM OPTIMIZATION AND SERIES FLEXIBLE ALTERNATING CURRENT TRANSMISSION SYSTEMS

Cat Swarm Optimization

Table.1 gives a comparison amongst three different optimization algorithms popular in implementation for power system stability problems by electrical engineers. Cat Swarm Optimization is observed to be best algorithm in finding global solution when in comparison with particle swarm optimization and Ant colony optimization [6]. Hence we have zeroed on implementation of Cat Swarm Optimization for our problem. In Cat Swarm Optimization, we first model the behaviour of cats into two sub-models, namely, seeking mode and tracing mode. Seeking mode is used to model the situation of the cat, which is resting, looking around and seeking the next position to move to. Tracing mode is the sub-model for modeling the case of the cat in tracing some targets. The algorithmic flow routine for the CSO can be explained through the flow chart in figure 1 [4].

Table 1: Comparison of ACO, PSO and CSO

Criteria	ACO	PSO	CSO
Communication Mechanism	Indirect communication mechanism among ants, called stigmergy, which means interaction through the environment	The communication among particles in PSO is rather direct without altering the environment	The communication among cats in CSO based on a swarm of N individuals, each evolving in M dimensions, using seeking and tracing modes
Speed and Accuracy	Low	Medium	High
In finding the global solution	Poor	Good	Very good
Examples of algorithm applications	Sequential ordering, Scheduling, assembly line balancing, Probabilistic TSP, DNA sequencing	Track dynamic systems, evolve NN weights, analyze human tremor, Register 3D to 3D biomedical image	Clustering problem, Graph colouring problem, IIR system identification, Image quality problem

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Vol. 5, Issue 3, March 2016

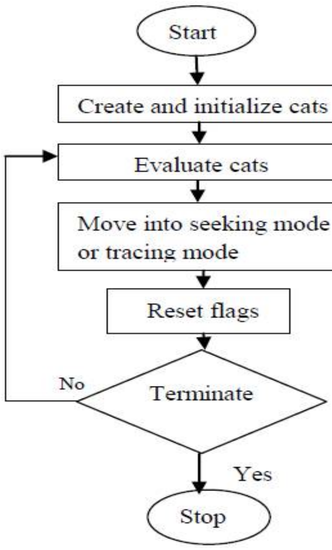

Figure 1: Flow chart for Cat Swarm Optimization

The steps in seeking mode shown in figure 1 are explained here.
1) Select the cats.
2) Assume a fixed range velocity for each cat.
3) Fitness values are calculated.
4) Select cats for availability in seeking mode.
5) Pick the cat randomly and apply in seeking mode in accordance to the following expression.

$$P_{kn} = [(1 \pm 0.3)\, R_{and}(\,)]*P_k \qquad (6)$$

Where, n = 1, 2, 3, 4, 5…..

$R_{and}(\,)$: is a random value in the range of [0, 1].

'P' is a pick-up of cat from a random set of cats and P_k is the total cat count available for application.

$$P_i = (FS_i - FS_b) / (FS_{max} - FS_{min}),\ 0 < i < j \qquad (7)$$

If the goal of the fitness function is to find the minimum solution,

$$FS_b = FS_{max},\ \text{otherwise } FS_b = FS_{min} \qquad (8)$$

Tracing mode models the case of the cat in tracing some targets. A cat which goes in tracing mode moves according to its own defined velocities for every dimension.
The steps in tracing mode shown in figure 1 are explained here.
1) Velocities for every dimension ($V_{k,d}$) are updated according to equation (9).
2) Check for velocities are in the range of maximum velocity. In case, new velocity is over range, then set it to be equal to the limit.
3) Update the position of cat_k to the best possible fitness value again. The process is continued till the best fitness value is obtained (also simultaneously, the cat location and the velocity).

$$V_{k,d} = V_{k,d} + r_1 \cdot c_1 \cdot (P_{best,d} - P_{k,d}),\ d= 1, 2,..., M \qquad (9)$$

Where $P_{best,d}$ is the position of the cat, which has the best fitness value.
$V_{k,d}$ is the velocity for every dimension.
$P_{k,d}$ is the position of cat_k, c_1 is a constant and r_1 is a random value in the range of [0, 1].

$$P_{k,d} = P_{k,d} + V_{k,d} \qquad (10)$$

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Series Flexible Alternating Current Transmission Systems

Static Synchronous Series Compensator (SSSC)

It is a static, synchronous generator operated as a series compensator as presented in figure 2. Its output voltage is in quadrature with the line current, and is controllable independently of it. Its purpose is to increase or decrease the overall reactive voltage drop across the line and thereby control the transmitted power. As observed in figure 2, it employs a step-down transformer. The leakage inductance forms the reactance in series with an ac/dc converter as shown. The controllable parameter is the magnitude V_s [5].

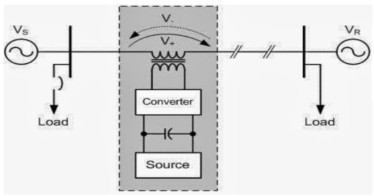

Figure 2: Static Synchronous Series Compensator

Thyristor Controlled Series Capacitor (TCSC)

TCSC shown in figure 3 is series type compensator, used to reduce the possibility of voltage collapse. TCSC is used to improve power flow capability of the line as well as to enhance system stability. To reduce the series reactive impedance and to minimize receiving end voltage variation series capacitive compensation is used [5].

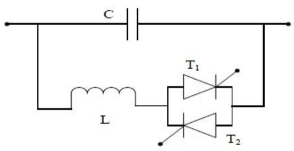

Figure 3: Thyristor Controlled Series Capacitor

V. IMPLEMENTATION, RESULTS AND DISCUSSION: A CASE STUDY BASED ON LINE OUTAGE CONTINGENCY

We are testing our swarm intelligence on IEEE 14 bus wind power network, the line diagram for which is presented in figure 4. Squirrel cage induction generators are coupled to fixed speed or constant speed wind turbines. The specifications of modified IEEE 14 bus wind power network include a total capacity of 259MW and 81.3 MVAR. The number of buses are fourteen of which eleven are load buses and the number of transmission lines are 16. Generators count is 5 with one slack bus. Bus number one is the slack bus. Constant speed wind turbines with squirrel cage induction generator being used. Base MVA of 100 is assumed for the test case.

Voltage collapse phenomenon under line outage contingency is taken as case study. Here line outage contingency is performed on the fourteen bus wind power network. It is an offline study. Contingency is outage of a power system component. It is a large disturbance that could possibly lead the system towards a black out. The detailed analysis is presented in table 2. According to the report we have considered the worst downfall of the bus voltages and applied the flexible alternating current transmission systems namely SSSC and TCSC with help of cat swarm intelligence to locate and size them to improve the voltage magnitude profile and loadability limit as defined in the objective function. Line outage-04, line outage-08 and line outage-09 were considered here to address the voltage stability problem as these are showing a steep downfall in the voltage magnitudes.

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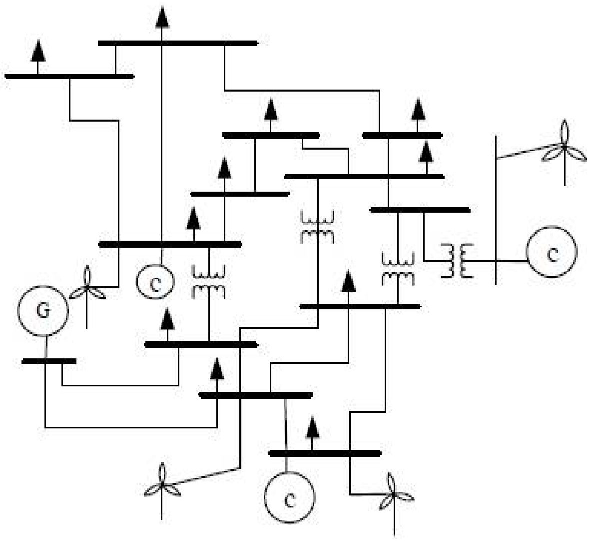

Figure 4: IEEE 14 bus network modelled with wind turbines

The parameters that constitute the dimensions of the position of the cat are listed as follows.

Number of iterations carried for CSO: 50
Number of cats used: 03
Number of cats in seeking mode: 02
Number of cats in tracing mode: 01

For line outage-04 contingency, the optimal location of SSSC devices is bus locations12-06, 13-12, 14-13 with sizes equal to 2.6kvar, 0.01kvar and 0.01kvar (λ_{max}=2.6735). For line outage-08 contingency the optimal location and optimal size of SSSC devices contingency is between the bus locations 09-07, 10-11, 11-06 with sizes equal to 0.01kvar, 0.01kvar, and 0.01kvar respectively (λ_{max}=3.0013). Finally for line outage -09 contingency the bus locations are 12-06, 13-12, 14-13 with var sizes equal to 0.01kvar, 6.2kvar and 0.01kvar (λ_{max}=3.0538).

The best location and optimal size of TCSC devices for line outage-04 contingency is concluded between buses 12-6, 13-12 and 14-13 with sizes is equal to 0.01kvar, 8.9kvar and 0.01kvar. The location of TCSC devices for line outage-08 contingency is zeroed between buses 9-7, 10-11 and 11-6 respectively. The sizes of TCSC devices are equal to 0.01kvar, 8.8kvar and 0.01kvar respectively. The best location and optimal size of TCSC devices for line outage-09 contingency is between buses 12-6, 13-12 and 14-13 with sizes is equal to 0.01kvar, 0.01kvar and 12.1kvar respectively.

Cat swarm optimization algorithm has given a better solution improving the voltage magnitude profiles as well as the maximum loading parameter in each case of line outage contingencies taken here. Cat swarm optimization technique has helped us in identifying the optimal location as well as size of two flexible alternating current transmission systems namely thyristor controlled series compensator and static synchronous series compensator. Cat swarm artificial intelligence which happens to be a meta heuristic search procedure is observed to be efficient technique in comparison to particle swarm and ant colony mimics.

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Table 2: N-1 Contingency Analysis report for 14 bus wind power network

	VOLTAGE MAGNITUDE PROFILE															
BUS NO.	LO -1	LO-2	LO-3	LO-4	LO-5	LO-6	LO -7	LO-8	LO-9	LO-10	LO -11	LO-12	LO-13	LO-14	LO-15	LO-16
1	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL
2	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL
3	0.54627	AL	0.6414	AL	AL	AL	0.647	AL	AL	0.57054	AL	0.58124	0.57939	AL	AL	AL
4	0.754	AL	0.842	AL	AL	AL	AL	AL	AL	AL	AL	0.7863	AL	0.8638	AL	AL
5	0.789	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	0.8319	AL	0.8336	AL	AL
6	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL	AL
7	AL	AL	AL	AL	0.8141	0.7807	AL	AL	AL	AL	AL	AL	0.7332	AL	AL	AL
8	AL	AL	AL	AL	0.7961	0.7501	AL	AL	AL	AL	0.6678	AL	AL	AL	AL	AL
9	AL	AL	AL	AL	0.79928	0.77216	AL	0.58668	AL	AL	0.7036	AL	0.72385	0.87449	AL	0.66294
10	AL	AL	AL	AL	AL	AL	AL	0.54488	AL	AL	AL	AL	AL	0.8484	0.7	0.65436
11	AL	AL	AL	AL	AL	AL	AL	0.5188	AL	AL	AL	AL	AL	AL	AL	AL
12	AL	0.65654	AL	0.59433	AL	AL	AL	AL	0.57345	AL	AL	AL	AL	AL	AL	AL
13	AL	0.65023	AL	0.58142	AL	AL	0.70029	AL	0.61875	0.73734	AL	AL	AL	AL	AL	AL
14	AL	0.64958	0.84663	0.57228	AL	AL	0.6677	AL	0.58254	0.71412	0.71129	AL	AL	0.85885	0.88903	0.52925

LO: Line Outage; **AL**: Acceptable Limit

The above mentioned FACTS devices were earlier tested with aforementioned swarm intelligence methods in [7] and [8]. In [7] authors have used PSO to address transient stability problem using SSSC. We have presented CSO instead to address voltage stability as this technique is fast in converging to the global best solution. In [8], authors have addressed optimal location and parameter setting of static var compensator and thyristor controlled series compensator using particle swarm optimization to mitigate small signal oscillations in a multi-machine power system. According to the comparison made in table 1, cat swarm optimization is better in reaching to global best result. In this case where two reactive power compensation devices namely SSSC and TCSC are used to address contingency condition in a power network, both are resulting in satisfactory results in voltage magnitude profile and maximum loading parameter as can been seen from tables 3 and 4 respectively with the help of CSO.

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Table 3: Voltage Magnitude Profile after CSO solution with SSSC's

Bus No.	Voltage profile before contingency without FACTS	Voltage profile after contingency for LO-4	Voltage profile after contingency with SSSC's using CSO	Voltage profile after contingency for LO-8	Voltage profile after contingency with SSSC's using CSO	Voltage profile after contingency for LO-9	Voltage profile after contingency with SSSC's using CSO
1	1.0575	1.058	1.058	1.0571	1.0581	1.0575	1.0592
2	0.94713	0.96193	0.90866	0.87141	0.9096	0.90111	0.99604
3	1.01	1.01	0.61792	0.63694	0.6224	0.73728	1.01
4	0.87394	0.81668	0.79784	0.73742	0.87736	0.75618	0.95265
5	0.89297	0.81431	0.86965	0.80883	0.91361	0.78554	0.97888
6	1.07	0.65435	1.07	1.07	1.07	0.69408	1.07
7	0.80459	0.84377	0.78897	0.63971	0.9894	0.6934	0.979
8	0.76841	1.09	0.7778	0.64989	0.98839	0.71874	0.8332
9	0.79139	0.71336	0.78752	0.58668	1.045	0.6449	0.83979
10	0.81295	0.6747	0.80672	0.54488	1.045	0.63448	0.84921
11	0.92704	0.65125	0.91958	0.51885	1.045	0.65496	0.94168
12	1.0058	0.59433	1.045	1.0011	1.0175	0.57345	1.045
13	0.971	0.58142	1.045	0.94992	1.0068	0.61875	1.045
14	0.80136	0.57228	1.045	0.6821	0.95405	0.58254	1.045
M.L.P (λ_{max})	2.8453	2.4343	2.6735	2.1041	3.0013	1.5434	3.0538

Table 4: Voltage Magnitude Profile after CSO solution with TCSC's

Bus No.	Voltage profile before contingency without FACTS	Voltage profile after contingency for LO-4	Voltage profile after contingency with TCSC's using CSO	Voltage profile after contingency for LO-8	Voltage profile after contingency with TCSC's using CSO	Voltage profile after contingency for LO-9	Voltage profile after contingency with TCSC's using CSO
1	1.0575	1.058	1.0588	1.0571	1.058	1.0575	1.058
2	0.94713	0.96193	0.97791	0.87141	0.906	0.90111	0.90488
3	1.01	1.01	1.01	0.63694	0.61117	0.73728	0.61843
4	0.87394	0.81668	0.92979	0.73742	0.87168	0.75618	0.85292
5	0.89297	0.81431	0.94633	0.80883	0.90969	0.78554	0.90395
6	1.07	0.65435	0.9675	1.07	1.07	0.69408	1.07
7	0.80459	0.84377	0.94209	0.63971	0.97905	0.6934	0.93231
8	0.76841	1.09	1.09	0.64989	0.97968	0.71874	1.09
9	0.79139	0.71336	0.84996	0.58668	1.045	0.6449	0.87444
10	0.81295	0.6747	0.82993	0.54488	1.045	0.63448	0.87965
11	0.92704	0.65125	0.87259	0.51885	1.045	0.65496	0.95754
12	1.0058	0.59433	1.045	1.0011	1.0174	0.57345	1.045
13	0.971	0.58142	1.045	0.94992	1.0069	0.61875	1.045
14	0.80136	0.57228	1.045	0.6821	0.9539	0.58254	1.045
M.L.P (λ_{max})	2.8453	2.4343	3.4596	2.1041	2.989	1.5434	2.8952

From the tables 3 and 4, though it is evident that the maximum loadability limit and voltage magnitude profile of the system buses are improved, in comparison to TCSC device, SSSC device is showing a greater improvement in terms of loadability limit as well as bus voltages. Hence it is suggested that SSSC be used where cost of installation is not a constraint.

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Vol. 5, Issue 3, March 2016

VI. CONCLUSION

In this paper, we have presented swarm intelligence based on behaviour of cats. A solution is obtained for voltage stability problems in wind power networks. Though ours is not the first paper to present cat swarm optimization, it happens to be the first one to address voltage stability issues arising in wind power networks under contingent conditions using the aforementioned algorithm. Cat swarm optimization in this case has worked wonders in scaling to down to global solution for determining the placement and size of flexible alternating current transmission systems with its lightning fast convergence in comparison to meta heuristic artificial intelligence techniques proposed earlier by many researchers. The results stress a point to use cat swarm optimization for all the advanced and practical power networks for mitigating unnecessary blackouts. Finally both SSSC and TCSC were showing encouraging results in improving system operating condition while maintaining stability limits.

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