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A Novel Approach for Power Loss & THD Reduction by Optimal Location of STATCOM in IEEE 14 Bus System Using PSO Algorithm

[1]Noopur Sahu; [2]Ankit Dubey; [3]Nidhi Singh

[1, 2, 3] *Department of Electrical and Electronics Engineering, Chhattisgarh Swami Vivekananda Technical University, Bhilai, Chhattisgarh, India*

[1]*noopur.sahu@dishamail.com*;[2]*ankit.dubey@dishamail.com*;[3]*nidhisinghjune@gmail.com*

ABSTRACT

This paper presents a novel method for optimal location of STATCOM in IEEE-14 bus system. In this paper, our aim would be finding optimal placement of STATCOM for voltage profile improvement, loss reduction, and THD (Total Harmonic Distortion) reduction in distribution & transmission networks. Particle Swarm Optimization (PSO) is used as the solving tool, where the problem is defined and the objective function is introduced. Taking into account the fitness values sensitivity in PSO algorithm process, it is desired to apply harmonic and load flow calculations for decision-making. Results show that the PSO is able to give the superlative solution with statistical significance and a great degree of convergence. A detail description of the method, results, conclusions and future scopes are also presented.

Keywords: Optimal location, Particle swarm optimization, STATCOM (static compensator), total harmonic distortion.

I. Introduction:

The subject of power transmission has always been an interest of researchers. A numerous methods have been developed to maximize the throughput of the systems. The controlling devices such as synchronous condensers, generators, reactors, tap changing transformers are used to minimize the losses. FACTS technologies offer competitive solutions to today's power systems in terms of increased power flow transfer capability, enhancing continuous control over the voltage profile, improving system damping, minimizing losses, etc. In this paper we have incorporated Static Synchronous Compensator (STATCOM) as the FACTS device to control the power loss in transmission lines. To optimize the device we forwarded our study to the optimization of STATCOM device by Particle Swarm Optimization. The model is structured in MATLAB and the performance comparison is presented in results. Heuristic methods represent the wide range of computable global optimization techniques that employs novel approaches for intelligent search of optimal values. These have common characteristics of natural evolution, physical processes and stochastic events.

Power systems components mainly consist of transmission lines, generators, switches, transformers, active or passive compensators and loads. Power system networks are complex systems that are non stationary, non-linear, and prone to faults and disturbances. Strengthening of a power system can be accomplished by increasing the transmission capacity, improving the voltage profiles and others. Nevertheless, some of these solutions may require considerable investment that could be difficult to recover. Flexible AC Transmission System (FACTS) devices are an alternate solution to address some of those problems.

Simple heuristic tactics are traditionally applied for determining the location of FACTS devices in a small power system. However, more scientific methods are required for placing and sizing FACTS devices in a larger power network. FACTS sizing and distribution constitutes a breakthrough problem in power systems due to multiple local minima and the overwhelming computational effort.

Nowadays, many Evolutionary Computation Techniques have been developed to determine the optimal placement of FACTS devices with promising results. Different algorithms such as Genetic Algorithms (GA) and Evolutionary Programming have been tried for finding the optimal allocation as well as the types of devices and their sizes.

Particle Swarm Optimization (PSO) is another evolutionary computation technique that can be used to solve the FACTS sizing and allocation problem. It has been applied to other power engineering problems such as: economic dispatch, generation expansion problem, short term load forecasting , and others, giving better results than classical methods and with less computational effort. In addition, it has been shown recently that the application of PSO is suitable in principle to optimally place FACTS devices in a multi machine power system to find out where the loss reduction and total harmonics distortion is minimum.

The main goal of this paper is to show the application of PSO for the optimal allocation of a Static Compensator (STATCOM), shunt FACTS device, in a power system. The criterion used in finding the best solution is to optimize the power flow of the .An IEEE-14 bus system work is used as an example to the methodology. In addition, the reduction in THD after using the PSO technique is also studied.

Basic concepts of Particle Swarm Optimization:

Particle swarm optimization (abbreviated as PSO) is a population based stochastic optimization technique given by Dr. Eberhart and Dr. Kennedy in 1995, motivated by social behavior of bird flocking or fish schooling. This algorithm originally intends to graphically simulate the graceful and irregular choreography of a bird folk. Each individual within the swarm is represented by a vector in multidimensional search space. This vector has also one assigned vector which determines the next movement of the particle and is called the velocity vector. The PSO algorithm also determines how to update the velocity of a particle.

It is based on the natural process of group communication to share individual knowledge when a group of birds or insects search food or migrate and so forth in a searching space, even though all birds or insects do not know where the best position is. But from the nature of the social behavior, if any member can find out a desirable path to go, the rest of the members will follow quickly.

The PSO algorithm is basically designed from animal's activity or behavior to solve optimization problems. In PSO, every single member of the population is called a 'particle' and the population is called a 'swarm'. Starting with a randomly initialized population and moving in randomly chosen directions, each particle goes through the searching space and remembers the best previous positions of itself and its neighbors. Particles of a swarm communicate good positions to each other as well as dynamically adjust their own position and velocity derived from the best position of all particles. The next step starts when all particles have been moved. Finally, all particles are likely to fly towards better and better positions over the searching process until the swarm move to close to an optimum of the fitness function f: $R^n \rightarrow R$. The PSO was originally developed for real valued spaces but many problems are, now, defined for discrete valued spaces where the domain of the variables is finite.

The PSO process is based on iteration a fixed number of times or until a minimum error based on desired performance index is achieved. The most optimist solution can be worked out in particle swarm optimization algorithm by the cooperation of each individual. The particle without volume and quality serves as each individual, and the simple behavioral pattern is synchronized for each particle to show the complexity of the whole particle swarm. This algorithm can be used to find out the complex optimist problems.

Particle Swarm Optimization Algorithm:

In the basic particle swarm optimization algorithm, particle swarm consists of "n" particles, and the position of every particle stands for the probable solution in D-dimensional space. The particles change its state according to the following three principles:

(1) To keep its inertia (2) to change the condition according to its most optimist position (3) to change the condition according to the swarm's most optimist position.

The position of each particle in the swarm is exaggerated both by the most optimist position during its movement (individual experience) and the position of the most optimist particle in its surrounding (near experience). When the whole particle swarm is surrounding the particle, the most optimum position of the surrounding is equal to the one of the whole most optimist particle; this algorithm is called the whole PSO and if the narrow surrounding is used in the algorithm, then this algorithm is called the partial PSO.

Each particle can be represented by its current speed and position, the most optimum position of each individual and the most optimist position of the surrounding. In the partial PSO, the speed and position of each particle change according the following equality:

$$v_{id}^{k+1} = v_{id}^{k} + c_1 r_1^k$$
$$(pbest_{id}^k - x_{id}^k) + c_2 r_2^k (gbest_d^k - x_{id}^k)$$

$$x_{id}^{k+1} = x_{id}^{k} + v_{id}^{k+1}$$

In these equations, v_{id}^k and x_{id}^k stand for separately the speed of the particle "i" at its "k" times and the d-dimension quantity of its position; $pbest_{id}^k$ shows the d-dimension quantity of the individual "i" at its most optimist positional "k" times. $gbest_d^k$ is the d-dimension quantity of the swarm at its most optimist position. In order to evade particle being far away from the searching space, the speed of the particle created at its each direction is limited between $-v_{dmax}$, and v_{dmax}. If the number of v_{dmax} is too big, the solution is far from the best, if the number of v_{dmax} is too small, the solution will be the local optimism; c_1 and c_2 shows the speeding figure, regulating the length when flying to the most particle of the entire swarm and to the most optimist individual particle. If the figure is too minimal, then the particle is probably far away from the target field, if the figure is too large, the particle will may be fly to the target field suddenly or fly beyond the target field. The proper figures for c_1 and c_2 can control the speed of the particle's flying and the solution will not be the partial optimism. Usually, c_1 is equal to c_2 and they are equal to 2; r_1 and r_2 represent arbitrary fiction, and 0-1 is an arbitrary number.

Parameters Of PSO Algorithm:

The implementation of PSO algorithm is discussed below and illustrated in the flow chart:

i) **Swarm size**: Swarm size or population size is the number of particles n in the swarm. A big swarm generates larger parts of the search space to be covered per iteration. A large number of particles may reduce the number of iterations need to obtain a good optimization result. In contrast, huge amounts of particles increase the computational complexity per iteration, and more time consuming. Or it is an apparently disorganized population of moving particles that tend to cluster together while each particle seems to be moving in a random direction.

ii) **Fitness function**: The PSO fitness function used to evaluate the performance of each particle corresponds to the objective function presented.

iii) **Particle**: It is basically represented by *X(t)*. It may be defined as a vector which contains the STATCOM bus location number.

Particle: [λ:η]

Where:

λ : is the STATCOM bus location number.

η: is the STATCOM size in MVAR.

iv) **Population or Number of particles**: There is a trade-off between the number of particles and the number of iterations of the swarm and each particle fitness value has to be evaluated using a power flow solution at each iteration, thus the number of particles should not be large because computational effort could increase dramatically. Or it is a set of n particles at time t, pop(t) = [$X_1(t)$,….$X_n(t)$]^T.

v) **Inertia weight**: The purpose is to improve the convergence of the swarm by reducing the inertia weight, generally shown by w(t). In other words it is a control parameter that is used to control the impact of the previous velocities on the current velocity. Hence, it influences the trade-off between the global and local exploration abilities of the particles.

vi) **Acceleration constants**: A set of three values for the individual acceleration constants are evaluated to study the effect of giving more importance to the individual's best or the swarm's best.

vii) **Particle velocity**: It is the velocity of the moving particles represented by an m-dimensional vector, represented by V(t).This component represents as a momentum which prevents to drastically change the direction of the particles and to bias towards the current direction.

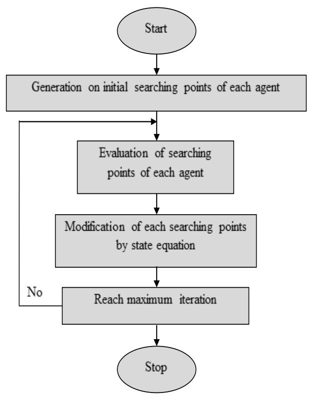

Fig.4.1.Flow chart of PSO algorithm

Static Synchronous Compensator (STATCOM):

A static synchronous compensator (STATCOM), also known as a "static synchronous condenser"

("STATCON"). It is a regulating device used on alternating current electricity transmission network system, based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network system. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. A Static Synchronous Compensator (STATCOM) is a member of the FACTS family that is connected in shunt with power system. The STATCOM consists of a solid state voltage source converter with GTO thyristor switches or other high performance of semi-conductor and transformer. The fundamental principle of a STATCOM installed in a power system is the generation ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor. The active and reactive power transfer between the power system and the STATCOM is caused by the voltage difference across the reactance. The STATCOM can also improve transient stability, damping low frequency oscillation, and increase transmission capacity. The STATCOM is represented by a voltage source, which is connected to the system through a coupling transformer. The voltage of the source is in phase with the ac system voltage at the point of connection, and the magnitude of the voltage is controllable. The current from the source is confined to a maximum value by adjusting the voltage.

The concept of STATCOM was proposed by Gyugyi in 1976. Power Converter employed in the STATCOM mainly of two types i.e. is Voltage Source Converter and Current Source Converter. In Current source Converter direct current always has one polarity and the power reversal takes place through reversal of dc voltage polarity whereas in Voltage Source Converter, dc voltage always has one polarity, and the power reversal takes place through reversal of dc current polarity. The power semiconductor devices used in current source converter requires bidirectional voltage blocking capability and for achieving this Characteristic an additional diode must be connected in series with a semiconductor switch which increased the system cost and its becomes costlier as compared to voltage source converter moreover Voltage source converter can operate on higher efficiency in high power applications. Because of the above reasons Voltage source converter is Preferred over Current source converter and now these days it act as a basic electronic block of a STATCOM that converts a dc voltage at its input terminals into a three-phase set of ac voltages at fundamental frequency with controllable magnitude and phase angle.

Basically a voltage-sourced converter based STATCOM generates ac voltage from a dc voltage. With the help of a voltage sourced converter, the frequency, the magnitude and the phase angle of the output voltage can be controlled. The fundamental principle of reactive power generation by a voltage-sourced converter is akin to that of the conventional rotating synchronous machine. From a dc input voltage source, the converter produces a set of controllable three-phase output voltages provided by the charged capacitor Cs with the system frequency of the ac power system.

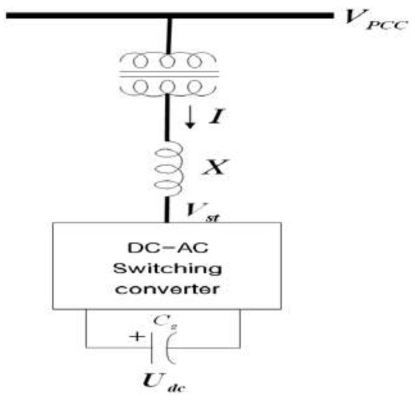

Fig.5.1 single-line diagram of var generator by rotating a voltage-sourced switching converter

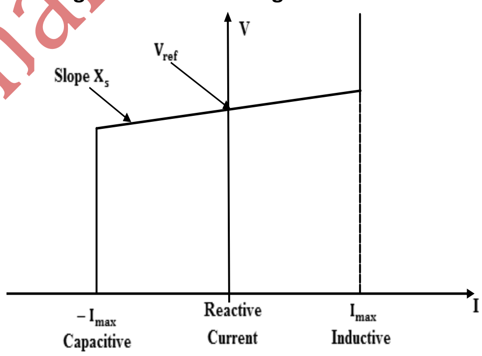

Fig.5.2. V-I characteristics of STATCOM

IEEE 14 Bus System

IEEE 14 bus system is used to test the power flow analysis without and with STATCOM. The IEEE14 bus test system is shown in Figure 6.1.

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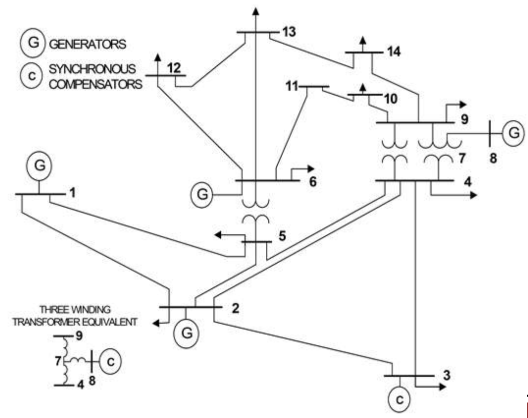
Line characteristics				
Line number	From Bus	To Bus	Line impedance (p.u.)	
			Resistance	Reactance
1	1	2	0.01938	0.05917
2	1	5	0.05403	0.22304
3	2	3	0.04699	0.19797
4	2	4	0.05811	0.17632
5	2	5	0.05695	0.17388
6	3	4	0.06701	0.17103
7	4	5	0.01335	0.04211
8	4	7	0	0.20912
9	4	9	0	0.55618
10	5	6	0	0.25202
11	6	11	0.09498	0.1989
12	6	12	0.12291	0.25581
13	6	13	0.06615	0.13027
14	7	8	0	0.17615
15	7	9	0	0.11001
16	9	10	0.03181	0.0845
17	9	14	0.12711	0.27038
18	10	11	0.08205	0.19207
19	12	13	0.22092	0.19988
20	13	14	0.17093	0.34802



Fig,6.1: Single line diagram of IEEE-14 Bus system

Here, the STATCOM is connected randomly at different buses. The voltage of all buses is heavily affected for the increasing load. The STATCOM is randomly connected and power flow losses for various buses are calculated to improve the voltage profile and also compensate the reactive power of whole system.

Initially the 14 bus system is tested without STATCOM. The approach can be taken into account for the unbalances of both network and load in 14 bus system. Now the loads of the other buses are considered and overall power generation is varied with increasing percentage from 40% to 100%. IEEE 14 bus system is now used to test the load flow analysis without and with STATCOM. For this analysis, the STATCOM is connected randomly in different buses there by verifying the real and reactive power variation.

Table (1)

LINES DATA

Table (2)

BUS DATA

Bus Number	Generation		Load	
	Real power (MW)	Reactive power (MVAR)	Real power (MW)	Reactive power (MVAR)
1	114.17	-16.9	0	0
2	40.00	0	21.7	12.7
3	0	0	94.2	19.1
4	0	0	47.8	-3.9
5	0	0	7.6	1.6
6	0	0	1.2	7.5
7	0	0	0	0
8	0	0	0	0
9	0	0	29.5	16.6
10	0	0	9.0	5.8
11	0	0	3.5	1.8
12	0	0	6.1	1.6

These lines and bus data are helpful for coding in PSO algorithm to find out the optimal location of

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STATCOM in reducing power loss as well as THD reduction.

Simulation Results:

The proposed PSO-based approach has been tested on the standard IEEE-14 bus system. The system line and data bus system are taken from the Refs.[17]. In this paper, first of all, power loss in IEEE-14 bus system has been measured without using STATCOM and then it is compared to power loss using STATCOM but without using PSO algorithm. Finally the variation is seen when STATCOM is placed using PSO algorithm iterations. Meanwhile, a reduction in THD is also presented. Table no.7.1 gives the simulated results and fig.7.2 gives the PSO convergence graph.

	Active power loss (MW)	Reactive power loss (Mvar)	THD
No STATCOM	29.3	99.4	1.73
STATCOM without PSO	28.1	1.58	1.7
STATCOM with PSO	23.3	96.3	1.58

Table..7.1: Comparison in power loss & THD reduction

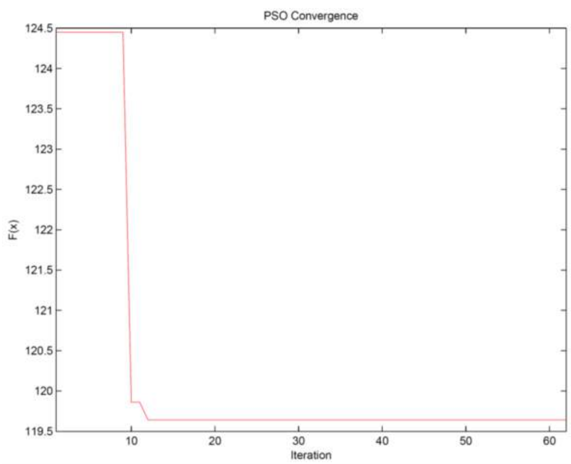

Fig.7.2: PSO convergence graph

Conclusions and Future Scope:

In the context of our research for the minimization of Transmission Power Losses by the application of FACTS devices, a comparison is made in the proposed approach. Particle Swarm Optimization is used to optimize the location of STATCOM using the MATLAB model. The tests were performed taking STATCOM as the FACTS device. The PSO algorithm has less power losses and much better than the line without STATCOM device.

In future various other different techniques can be carried out for the power factor correction methodologies based on fuzzy control. Experimental investigations can be done on shunt active power filter by developing a prototype model in the laboratory to verify the simulation results for fuzzy controller. Modelling and further verification can lead to the generation of new approach a step further in this work.

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