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OPTIMAL PLACEMENT OF STATCOM FOR IMPROVING VOLTAGE STABILITY USING GA

[1]SAKET SAURABH, [2]MD IRFAN AHMED

[1]Student M.Tech (Power System), Department of Electrical Engineering, National Institute of Technology Patna, Bihar, India, Email: Saket_saurabh@outlook.com
[2]Student M.Tech (Power System), Department of Electrical Engineering, National Institute of Technology Patna, Bihar, India, Email: irfanmits.ahmed@gmail.com

ABSTRACT

Voltage stability enhancement plays a vital role in power system. Depending upon the type of loading and environmental conditions the voltage stability can be categorized as transient stability and steady state stability. In this work steady state stability has been taken in to account. It shows the voltage stability enhancement which will further lead to improvement in the system performance, reduction of the losses, and making the system more secure. Out of the various means for enhancing stability, in this paper Static Synchronous Controller (STATCOM) devices have been employed which proved to be flexible, reliable and provides desired characteristics. This paper discusses the comparative result before application of STATCOM and after optimal placement of STATCOM in the system network. In the first stage Newton Raphson (NR) method is used to determine voltage magnitude and phase angle at every node of the IEEE 14 bus system with and without STATCOM. In the second stage Genetic Algorithm (GA) finds the optimal location for placing the STATCOM. After placing the STATCOM the losses is reduce. The proposed method is tested on IEEE 14 bus system using MATLAB.

Index Terms: *Static Synchronous Controller (STATCOM), Flexible AC Transmission System (FACTS), Genetic Algorithm (GA), and Newton Raphson (NR)*

1. INTRODUCTION

Voltage stability is an area where approach and resources are very much domain dependent. Power demand plays a vital role to maintain the voltage stability in power system network. Problem in a system is raised when the demand of power increases because the system does not have the sufficient reactive power. So, the problem of overvoltage, losses, insecurity, and voltage instability, collapse and deregulation starts rising and performance of the system is affected and causes the blackout. In this paper the main problem is sudden change in power demand is not capable of providing sufficient reactive power to the system. So, it is difficult to maintain the voltage at each bus within the limits, security of the system, and the losses in the system are increasing, which is making our system deregulated and causing the problem of blackout. By improving the voltage stability which may result in smooth working of the network and the problem of blackout can be avoided. Since 1920's there are various techniques are used to overcome, the problem of voltage instability but it's not effective. So, the new methodology have been used i.e. Flexible AC Transmission System (FACTS) was adopted.

FACTS are the new power electronics based devices, established for enhancing the voltage stability. It focuses on the losses, cost, power, security and voltage profiles of in the network [3]. So, STATCOM type FACTS device are used in this paper to solve the problem. GA is used for the optimal location of FACTS devices.

2. VOLTAGE STABILITY ENHANCEMENT

Nowadays the increasing population is causing the problem in power system by increasing the power demand continuously. As the increase in power demand beyond its given limit causes the insufficient supply or too much absorption of reactive power in the system. The incapability of the system to maintain reactive power is causing the problem of voltage instability. The common form of voltage instability is the continuous decline in the bus voltages, increase in losses and system becomes vulnerable [1].
Voltage stability is basically the capability of the system to maintain the bus voltages within its limit under normal condition and after being subjected to the disturbances.

2.1 Causes of Voltage Instability

- Increment of load is the reason for the voltage at the buses to decline.
- Reduction of power generation
- Outage of apparatus and lines
- Voltage control mechanism failure.
- System supply or absorbs insufficient reactive power.

2.2 Methods to Enhance Voltage Stability

- Excitation of the generators is improved.
- Regional grids can be connected by using HVDC.
- Synchronous condensers can be used.
- Lines are compensated.
- Inertia of generating unit is improved.

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3. FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

Phase shifting transformers, tap changing transformers etc. are the devices which were earlier used for voltage stability in a power system network. These methods are too complex and do not provide the reliable, efficient and fast response [3]. Hence, FACTS system is a power electronics based controller used in ac transmission system for improving controllability and power system capability. FACTS are not the single controllers but the collection of controllers.

Classification of FACTS controllers are:

1. Series Controllers
2. Shunt Controllers
3. Series-Shunt Controllers

3.1 Series Controllers

It is used for injecting the voltage in series with the line. It supplies reactive power when the injected voltage gets in phase quadrature else it deals with the real power. It is used for long distance lines. Series Controllers implies the fractional neutralization of the transmission line reactance by a capacitor bank installed in series with line.

Series Controllers are of three types:

1. Thyristor Controlled Series Controller (TCSC)
2. Static Synchronous Series Controller (SSSC)
3. Thyristor Switched Series Controller (TSSC)

3.2 Shunt Controllers

It is used for injecting the current in the line. It supplies reactive power when the injected currents gets in phase quadrature with the line voltage else it deals with the real power.

Shunt Controllers are of two categories:

1. Static Synchronous Controller (STATCOM)
2. Static VAR Controller (SVC)

3.2.1 Static Synchronous Controller

A static synchronous generator operated as a shunt connected static VAR controller whose capacitive or inductive output current can be controlled independent of the ac system voltage [6]. It is based on voltage source or the current source converter. Voltage source converter is preferable by considering cost as the important. STATCOM is also used as the active filter for reducing or absorbing the harmonics.

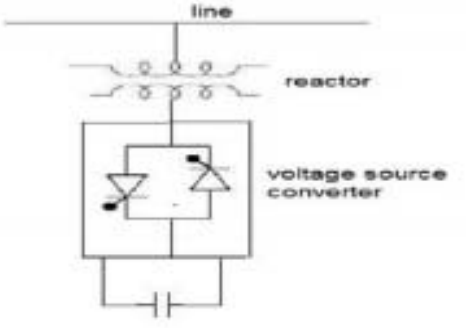

Figure 1: STATCOM Layout

3.3 Series-Shunt Controllers

It is the combination of both Shunt and Series type Controllers. So, it shows the characteristic of both types of controllers and it is used for both power flow and voltage profiles, reduce the losses, and makes the system more reliable, flexible, and secure. The type of series-shunt controller is Unified Power Flow Control (UPFC).

3.4 Featurers of STATCOM

- STATCOM functions as shunt connected synchronous voltage source.
- STATCOM provides better performance.
- STATCOM provides faster response than Static Var Controller (SVC).
- Superior functional characteristics
- STATCOM has no delay allied with the thyristor firing.
- Greater flexibility
- Low system voltage supports full capacitive output current.
- At low voltages STATCOM breeds more reactive power because, capacitive power generated α system voltage. Hence in STATCOM capacitive power generated varies linearly with system voltage.

3.5 Advantages of FACTS

- Reduces the losses
- Voltage fluctuation is controlled with the help of STATCOM.
- Power carrying capacity of the line is improved.
- Transient stability is ameliorated.
- Improves quality of supply
- Superior use of the existent transmission system
- Diminishes the reactive power flow

4. PROBLEM FORMULATION

In the First stage, the voltage and Phase angle at each bus in both the systems are identified, and the first bus in both the systems are considered to be the slack bus with its values as $1\angle 0$ p.u and other may be the load bus or the generator bus. The voltage magnitude and phase angles are calculated using load flow analysis [5] i.e. NR method. Now FACTS devices are optimally placed in the system using GA technique.

4.1 Newton Raphson Method (NR)

NR method is used for solving the nonlinear algebraic equations. It provides fast response and sure convergence as compared to Gauss Seidel method.

Power flow equations [2]:

$$P_i \text{ (Real Power)} = | V_i | \sum_{j=1}^{m} (|V_j||Y_{ij}|\cos(\phi_{ij} + \delta_j - \delta_i))$$

$$Q_i \text{(Reactive Power)} = -| V_i | \sum_{j=1}^{m} (|V_j||Y_{ij}|Sin(\phi_{ij} + \delta_j - \delta_i))$$

Where,

V_i = voltage at i^{th} bus

V_j = voltage at j^{th} bus

Y_{ij} = admittance of i^{th} and j^{th} bus

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ϕ_{ij} = angle of the admittance

Δ_j = phase angle of the j^{th} bus
Δ_I = phase angle of the i^{th} bus

J is the jacobian matrix which is used for solving the NR method.

$$J = \begin{bmatrix} \frac{dp}{d\delta} & \frac{dp}{|V|} \\ \frac{dQ}{d\delta} & \frac{dp}{|V|} \end{bmatrix}$$

Y_{ij} bus matrix

$$Y_{bus} = \begin{bmatrix} Y_{11} & .... & Y_{ij} \\ .... & .... & .... \\ Y_{ji} & .... & Y_{jj} \end{bmatrix}$$

4.2 Iteration

Step 1: Consider one bus is slack bus in a system whose voltage and phase angle are $1\angle 0$ and assume the all other buses as PQ and PV buses.
Step 2: In the r^{th} iteration,

$$P_i^r = |V_i|^r \sum_{j=1}^{m} (|V_j||Y_{ij}|\cos(\phi_{ij} + \delta_j - \delta_i))$$

$$Q_i^r = -|V_i|^r \sum_{j=1}^{m} (|V_j||Y_{ij}|\sin(\phi_{ij} + \delta_j - \delta_i))$$

Let,

$$e_i^r = |V_i|^r \cos\delta_i^r \quad \text{And} \quad f_i^r = |V_i|^r \sin\delta_i^r$$

$$G_{ij} = |Y_{ij}|\cos\phi_{ij}$$

$$B_{ij} = |Y_{ij}|\sin\phi_{ij}$$

Then Calculate,

ΔP_i^r =P_i (scheduled) - P_i^r for PV and PQ buses

ΔQ_i^r =Q_i (scheduled) - Q_i^r for PQ buses

Here if all the values of ΔP_i^r and ΔQ_i^r are less than the tolerance, iterations are stopped, calculate P1 and Q1 and the solution is obtained.
Step 3: If the convergence criteria is not obtained, calculate the Jacobian matrix elements.
Step 4: correction of voltage magnitude and phase angles.
Step 5: Next update the voltage magnitude and phase angles.

$$|V|^{(r+1)} = |V|^r + \Delta|V|^r$$

$$\delta^{(r+1)} = \delta^r + \Delta\delta^r$$

Again go to step 2 and continue the process unless the convergence is obtained.

4.3 Genetic Algorithm (GA)

In 1960 I. Rechenberg introduced the idea of evolutionary computing in his work Evolutionary strategies. GA's are computerized search and optimization algorithms based on mechanics of natural genetics and natural selection.

In the domain of artificial intellect, GA is a search heuristic that follows the natural selection process. This heuristic approach is also called meta-heuristic i.e. used to form serviceable solutions to optimization and search problems [4]. The solutions to optimization are generated by using this selection technique such as, mutation, crossover and selection.

1. Selection:

Selection is the part of GA where the individual's genes are selected from population.

2. Crossover:

It is used for changing chromosomes from one generation to another. It is the process where different individuals are selected as parent solutions and they produce children solution.

Methods of Crossover:

One point Crossover: - For both parents single crossover point is selected. All the data available after the crossover point is exchanged between parents.

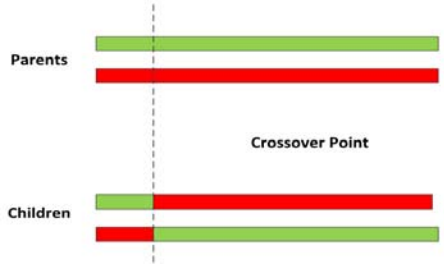

Figure 2: One Point Crossover

Two Point Crossover: - For both parents two crossover points. All the data available after the crossover point is exchanged between parents.

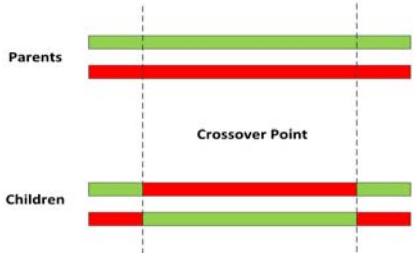

Figure 3: Two Point Crossover

Cut and Split: - This shows change in length of child string, because each parent string is separated at different crossover point.

Figure 4: Cut and Split Point Crossover

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3. Mutation:

It is used to maintain genetic diversity from one generation to next generation. Mutation changes one or more gene values from their initial ones in chromosome and a result obtained in mutation is totally different from the last solutions [4].

4. Fitness Function:

Due to the Fitness function result is in the form of single figure called figure of merits. After every round of testing, previous worst design solutions are deleted and new ones are raised.

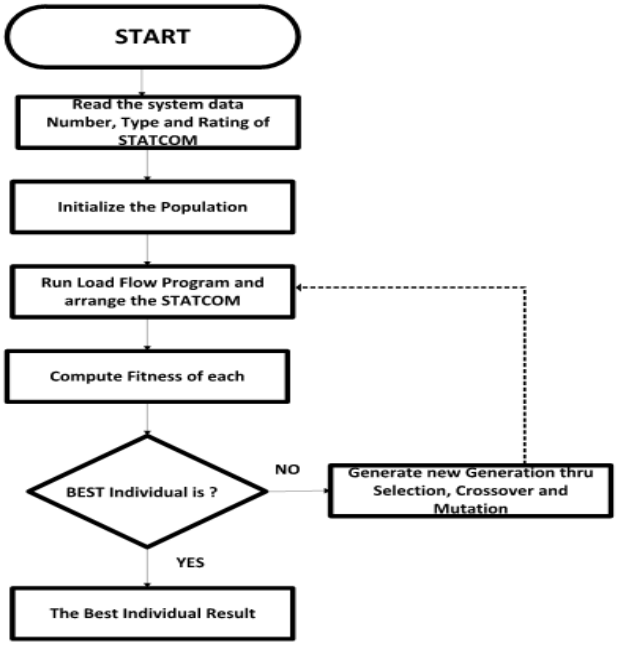

Figure 5: Flow Chart of GA

4.4 Advantages of GA

- It can vary both the values and structure and the desired result can be obtained.
- Quick response for acceptable solution
- It deals with the large number of solution.

4.5 Algorithm

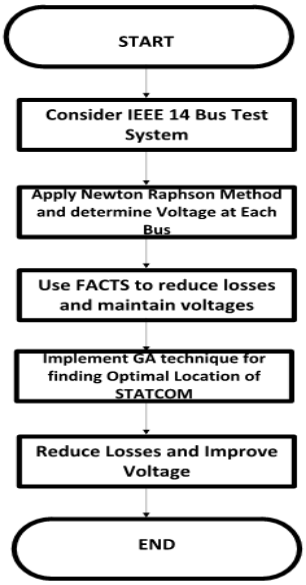

Figure 6: Algorithm of Optimal Placement of STATCOM for improving Voltage stability using GA

5. RESULTS

The comparative result before the application of STATCOM and after optimal placement of STATCOM in the system network has been discussed. NR method is used to determine voltage magnitude and phase angle at every node of the IEEE 14 bus system with and without STATCOM. GA finds the optimal location for placing the STATCOM. After placing the STATCOM the losses got reduced.

5.1 Voltage and Phase angle of IEEE 14 bus system using NR method

The voltage and phase angle is calculated at each bus using NR method as shown in Table 1.

Table -1: Voltage and Phase angle of IEEE 14 bus system using NR method

Bus No.	Voltage (pu)	Angle (degree)
1	1.0300	0.0000
2	0.9830	-5.5790
3	0.8956	-14.0697
4	0.9125	-11.0985
5	0.9239	-9.3695
6	0.9141	-16.4834
7	0.8995	-15.0345
8	0.8995	-15.0345
9	0.8836	-17.2196
10	0.8801	-17.4841
11	0.8928	-17.1532
12	0.8956	-17.6413
13	0.8891	-17.7069
14	0.8644	-18.8546

5.2 Determine Voltage, Phase angle and Losses using GA

The voltages, phase angles and losses of the system are calculated using GA with and without STATCOM for Optimal Location of STATCOM.

Table -2: Voltage and Phase angle with and without STATCOM using GA

Bus No.	WITHOUT STATCOM		WITH STATCOM	
	Voltage (pu)	Angle (degree)	Voltage (pu)	Angle(degree)
1	1.0000	0.0000	1.0000	0.0000
2	0.9450	-5.3015	0.9450	-5.3005
3	1.0100	-16.1049	1.0100	-16.1026
4	0.9222	-11.7089	0.9226	-11.7099
5	0.9246	-9.7250	0.9250	-9.9713
6	0.9560	-17.3053	0.9560	-17.2908
7	0.8874	-15.3993	0.8882	-15.4023
8	0.8440	-15.3993	0.8440	-15.4023
9	0.8869	-17.4622	0.8876	-17.4645
10	**0.8904**	-17.7955	**0.8930**	-17.8125
11	**0.9186**	-17.6834	**0.9220**	-17.7391
12	0.9352	-18.3798	0.9356	-18.3655
13	0.9259	-18.3795	0.9264	-18.3673
14	0.8828	-19.2272	0.8833	-19.2212

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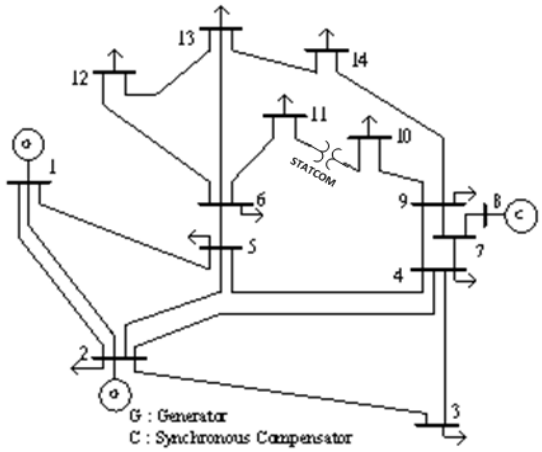

Figure 7: IEEE 14 bus system with STATCOM

In IEEE 14 bus system the Optimal Location of STATCOM has been identified by the GA hence, it can be seen that the voltage (pu) is increased from 0.9186 to 0.9220 at bus number 11 as shown in Table 2 and in Figure 7. So, the optimal placement of STATCOM is at bus number 11. The voltage profile at different scenario of IEEE 14 bus system as shown in Figure 8

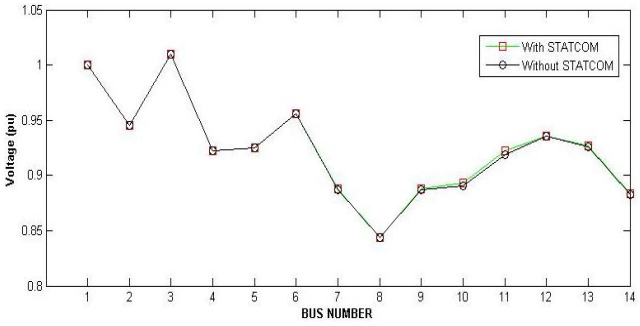

Figure 8: Voltage Profile of IEEE 14 bus system with and without STATCOM

Table -3: Losses with and without STATCOM

Losses without STATCOM in MW	Losses with STATCOM in MW
20.764	20.722

Hence it is shown in Table-3 that with the optimal placement of STATCOM in the system the voltage at buses is improved and losses are reducing hence, voltage stability is enhanced.

6. CONCLUSION

The common feature of voltage instability is the decline in the bus voltage which further leads to blackouts. Load flow analysis using NR method has been employed to determine the magnitude of voltages and phase angles at buses. Determining voltages at the buses enables the power system operators to decide the remedial actions. In order to maintain the bus voltages, STATCOM are placed in the system. A meta-heuristic software computing technique called GA has been adopted to identify the optimal location of STATCOM. This technique is also used for optimizing the parameters of the GA such as Mutation rate, Crossover rate and population size. The optimization results obtained for IEEE 14 bus test system are analyzed and the result obtained shows the reduction in the system losses, cost of generation besides improving the voltage at the buses.

6.1 FUTURE WORK

Improvement in voltage stability is a wide area and there is vast research scope in this direction such as

1. The maintenance of voltage at buses can also be done under dynamic conditions by considering different contingency conditions.
2. Location of FACTS devices for voltage stability enhancement can be done by other advanced heuristic methods such as Bee Colony, Harmony Algorithm or the Gravitational Algorithm.
3. Multi- Type FACTS devices can be used for improving voltage stability and reducing losses.

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BIOGRAPHIES

Saket Saurabh, M.Tech (Power System), Research area: Induction Motor, Power Electronics

Md Irfan Ahmed, M.Tech (Power System), Research area: DG, Deregulated Electricity Market