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Transient Stability Enhancement by Optimal Location and Tuning of STATCOM using PSO

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Abstract

Transient stability enhancement via optimal location and tuning of STATCOM is thoroughly investigated in this paper. The performance analysis of STATCOM has been executed for Western Science Coordinated Council (WSCC) 9 bus system for the enhancement of transient stability using Power System Analysis tool box (PSAT) software. The proposed Particle Swarm Optimization (PSO) algorithm technique, location of the STATCOM device and parameter value is optimized simultaneously. The performance of STATCOM (Static Synchronous Compensator) is implemented through the nonlinear time-domain simulation. The results are compared with the Particle Swarm optimization based tuned STATCOM. The proposed algorithm is very effective and analyzed using PSAT software.

Keywords: STATCOM, Transient stability, PSO

1. Introduction

In order to improve the stability of the system, FACTS (Flexible AC Transmission Systems) are developed in recent years. FACTS devices are used to inject or absorb the reactive power. FACTS are used to improve power system operation control power transfer. STATCOM is one of the FACTS devices which are used to regulate the system voltage by absorbing and injecting reactive power [1].

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It consists of a voltage source inverter which generates controllable ac voltage source behind a transformer leakage reactance and a energy storage capacitor. The damping of low frequency oscillations using PSS and STATCOM is proposed in some papers. Optimal power flow and reactive power compensation is proposed in some papers [2]. Some papers are presented for power system stability enhancement. The optimal location and tuning of STATCOM has an essential role to enhance the stability. This paper presents the investigation of best location and tuning of STATCOM to enhance the transient stability for three phase fault conditions. The performance of the proposed controller is carried out by the time domain simulation [3] [4].

2. Transient stability with STATCOM

The power system has to maintain synchronism when subjected to severe transient disturbances. Here, the disturbances might be a fault, loss of generation or loss of a big load. The disturbances affect the rotor angles, bus voltages, power flows and many variables of the system. This paper investigates the effect of fault on bus voltages occurred in the system. A current injection model of STATCOM has been implemented in PSAT. The reactive power exchange happens between AC system and STATCOM, because of the current is always kept in quadrature to the bus voltage. The reactive power

\[ Q = I_{sh}V \]  

(1), Where \( I_{sh} \) = current of the STATCOM which will be injected to system.

![STATCOM circuit block diagram](image)

Fig.1  STATCOM circuit block diagram

\[ K_r = \text{Regulator gain.} \quad T_r = \text{Regulator time constant.} \]

Fig.1 shows the STATCOM block diagram. A STATCOM can improve the power system performance through the Voltage flicker control, Transient stability, Power oscillation damping, dynamic voltage control and Reactive power control. Among this, transient stability of the system is considered to study using STATCOM in this paper. STATCOM occupies less space by compact electronic converters [5] [6]. It also minimizes the environmental impact by using electronic converters.

3. Particle swarm optimization (PSO)

It is a simple and robust method based on the social behavior of the species like bird flocking, fish schooling etc. The PSO places the particles in the search space with initial velocities. The velocities are assigned to the particles randomly. Each particle in search space will find optimal solution with the help of two parameters. The two parameters are velocity and position [7]. By the help of the two parameters, the fitness function of the particle has been calculated. Each particle in the problem space would have its best solution. From the ref. [8], transient stability analysis has been done by UPFC using PSAT. According to this paper, transient stability analysis has been done by STATCOM and the parameters of the STATCOM has been tuned by PSO algorithm. That best value is called as \( P_{best} \). When a particle completes its population, then the best value is global best (Gbest). After finding the two best values, the particle updates its velocity and position according to the following equations.

\[ V_{t+1}^{k+1} = W_t V_t^k + C_1^*rand_1^* (P_{best} - S_t^k) + C_2^* rand_2^* (G_{best} - S_t^k) \]  

(2)

\[ S_t^{k+1} = S_t^k + V_t^{k+1} \]  

(3)
\( V_i^k \) = Velocity of agent \( i \) at \( k^{th} \) iteration, \( V_i^{k+1} \) = Velocity of agent \( i \) at \( (k + 1)^{th} \) iteration

\( W_k \) = The inertia weight, \( C_1 \) and \( C_2 \) = Individual and social acceleration constants (0 to 3)

\( rand_1 \) & \( rand_2 \) = random numbers (0 to 1), \( S_i^k \) = Position of agent \( i \) at \( K^{th} \) iteration

\( S_i^{k+1} \) = Position of agent \( i \) at \( (K + 1)^{th} \) iteration, \( P_{best} \) = Particle best of agent \( i \)

\( G_{best} \) = Global best of the group

4. Objective function for STATCOM

A robust tuning method is necessary to increase the system damping over different operating conditions. So, the design of STATCOM parameters has been formulated as an Eigen value based objective function. Here, two sub objective functions are used. One is minimization of the real part of the Eigen value and the other one is maximization of the damping ratio. The damping ratio of the \( i^{th} \) critical mode

\[
\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \frac{-\omega_i}{\sqrt{\sigma_i^2 + \omega_i^2}}
\]

(4)

Where the eigen value \( \lambda_i = \sigma_i \pm j\omega_i \) . The objective functions are represented as,

\[
J_1 = \sum_{i=1}^{n} (\sigma_i - \sigma_0)^2 \sum_{i=1}^{n} (\omega_i - \omega_0)^2
\]

(5),

\[
J_2 = \sum_{i=1}^{n} (\zeta_i - \zeta_0)^2
\]

(6)

where \( \sigma_i \leq \sigma_0 \), \( \zeta_i \geq \zeta_0 \) for \( i = 1, 2, \ldots, n \). The combined objective function \( J = J_1 + \alpha J_2 \) is used to have a closed loop eigen values . The value of \( \alpha \) is considered as 7.

Fig. 2 shows th objective function of the system.

5. Particle swarm optimization algorithm

\textit{Step 1:} Initialize each particle’s velocity and position. \textit{Step 2:} Calculate the fitness value using the objective function and determine the \( P_{best} \). \textit{Step 3:} Determine \( G_{best} \) from the \( P_{best} \). \textit{Step 4:} Update the velocity and position. \textit{Step 5:} Check the solution is feasible or not. \textit{Step 6:} If the solution is feasible, check the iteration count. \textit{Step 7:} If the iteration count reaches the maximum, stop the process. \textit{Step 8:} If the iteration count does not reach the maximum, then continue the process from 2-7. Fig. 3 shows the flowchart for the algorithm. Table 1 gives the details of PSO parameters. The fitness function can be varied depends upon the problem occur in the system. STATCOM parameters \( K_r, T_r \) are selected to tune as per algorithmic procedure. In this paper, Western Science Coordinated Council (WSCC) 9 bus system is considered under study with and without fault.
6. Analysis of fault in WSCC 9 bus system

The time domain simulations are done in PSAT software which is used to compute and plot the graphs of the system. The performance of the STATCOM can be evaluated through the system which is selected to work out and the case studies. A 9 bus system (WSCC -Western Science Coordinated Council) with 6 transmission lines, 3 generators, 3 loads and a local load D is considered to study.

![Voltage profile of the system without STATCOM](image)
6.1 Loading of WSCC 9 bus system

The system performance has been studied by applying a 3 phase fault. The fault time at 1.05s and clearing time 1.15s. The fault has been applied at the bus 6 of the system. The loading conditions for the system (per unit) are given in Table 2. Fig. 4 shows the voltage profile without STATCOM.

Table 2. Loading condition of the system

| Load   | P    | Q    |
|--------|------|------|
| Load A | 2.00 | 0.90 |
| Load B | 1.80 | 0.60 |
| Load C | 1.60 | 0.65 |
| Load D | 1.60 | 0.65 |

6.2 Fault analysis with 9 bus system

After the first case, the bus 5 and bus 6 have been affected severely and the system has low voltage profile because of the fault. According to this case, the optimal location of STATCOM is bus 5 and bus 6. Here, STATCOM has been applied at bus 6 to improve the system stability. (The parameters of un tuned STATCOM are - 50 for $K_r$ and 0.001 for $T_r$). Fig. 5 and Fig. 6 show the voltage waveforms of the bus 5 and bus 6. Table 3 shows the performance indices of the system without STATCOM. Fig. 7, Fig. 8 and Fig. 9 show the voltage profile, bus 5 voltage, bus 6 voltage with STATCOM respectively.

![Bus 5 voltage without STATCOM](image1)

Table 3 Performance indices without STATCOM

| Bus   | V [p.u.] | phase [rad] | P gen [p.u.] | Q gen [p.u.] | P load [p.u.] | Q load [p.u.] |
|-------|----------|-------------|--------------|--------------|---------------|---------------|
| Bus 1 | 1.04006  | 12.0285     | 4.62488      | 2.01569      | 1.6           | 0.65          |
| Bus 2 | 1.02504  | 11.8744     | 1.63         | 0.62432      | 0             | 0             |
| Bus 3 | 1.02505  | 11.7956     | 0.85         | 0.42558      | 0             | 0             |
| Bus 4 | 0.97888  | 11.8566     | 0            | 0            | 0             | 0             |
| Bus 5 | 0.91728  | 11.7108     | 0            | 0            | 2             | 0.9           |
| Bus 6 | 0.93421  | 11.7197     | 0            | 0            | 1.6           | 0.65          |

![Voltage profile with STATCOM](image2)
The reactive power 0.65749 p.u injection has been done by STATCOM. Table 4 shows the performance indices with STATCOM.

| Bus | V phase [p.u.] | P gen [p.u.] | Q gen [p.u.] | P load [p.u.] | Q load [p.u.] |
|-----|----------------|--------------|--------------|---------------|---------------|
| 1   | 1.04098        | 4.61375      | 1.56254      | 1.6           | 0.65          |
| 2   | 1.0262         | 1.63         | 0.48664      | 0             | 0             |
| 3   | 1.03123        | 0.85         | 0.15559      | 0             | 0             |
| 4   | 1.01896        | 0            | 0            | 0             | 0             |
| 5   | 0.95011        | 0            | 0            | 2             | 0.9           |
| 6   | 1.04451        | 0.65749      | 1.6          | 0.65          |

The STATCOM parameters $K_r$ and $T_r$ have been tuned by Particle swarm optimization and the voltage profile of bus 5 voltage, bus 6 voltage have been plotted. Particle Swarm Optimization Tuned parameters are:

$K_r = -5.0113$

$T_r = 0.038862$

The voltage profile, bus 5 voltage, bus 6 voltage have been plotted after the STATCOM parameters are tuned. The STATCOM has been applied at bus 6 of the system. STATCOM is used to improve the stability of the system.
Fig.10 shows the voltage profile of the system with Tuned STATCOM. Fig.11 and Fig.12 show the corresponding voltage waveforms of the bus 5 and bus 6. The reactive power 0.65749 p.u injection has been done by STATCOM. It is shown in Table 5 that STATCOM tuned by PSO gives the improved voltage profile of the system. Table 6 gives the comparison results of voltage profile in all cases.

Table 5 Performance indices With STATCOM (Tuned by PSO)

| Bus    | V phase [p.u.] | P gen [p.u.] | Q gen [p.u.] | P load [p.u.] | Q load [p.u.] |
|--------|----------------|--------------|--------------|---------------|---------------|
| Bus 1  | 1.04034 -91.745 | 4.61375      | 1.56254      | 1.6           | 0.65          |
| Bus 2  | 1.02578 -91.888 | 1.63         | 0.48664      | 0             | 0             |
| Bus 3  | 1.02803 -91.967 | 0.85         | 0.15559      | 0             | 0             |
| Bus 4  | 1.01036 -91.916 | 0            | 0            | 0             | 0             |
| Bus 5  | 0.94383 -92.053 | 0            | 0            | 2             | 0.9           |
| Bus 6  | 1.02006 -92.053 | 0            | 0.65749      | 1.6           | 0.65          |

Table 6 Comparison of voltage profile

| Bus    | Without STATCOM (Untuned) V in p.u | With STATCOM (Tuned by PSO) V in p.u |
|--------|------------------------------------|-------------------------------------|
| Bus 1  | 1.04006                            | 1.04098                             |
| Bus 2  | 1.02504                            | 1.0262                             |
| Bus 3  | 1.02505                            | 1.03123                             |
| Bus 4  | 0.97888                            | 1.01896                             |
| Bus 5  | 0.91728                            | 0.95011                             |
| Bus 6  | 0.93421                            | 1.04451                             |

7. Conclusion

The performance of STATCOM in PSAT has been investigated through the time domain and power flow simulations. The optimal location and tuning of the STATCOM improves the system's transient stability. The voltage profile and bus voltage graphs show increase in voltage and transient stability of the system when STATCOM is used. Based on this work, the performance of the STATCOM tuned by PSO and un tuned parameters of STATCOM are almost same. In the future work, the fault time will be increased and the performance of the STATCOM tuned by PSO would give better voltage profile than the un tuned STATCOM. The results are compared with the PSO tuned STATCOM and un tuned system.

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