# A hybrid SATS algorithm based security constrained optimal power flow using FACTS devices

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**ABSTRACT**

In the realm of power systems, achieving optimal operation while ensuring security remains a paramount challenge. The security constrained optimal power flow (SCOPF) problem deals with optimizing power system operations while taking into account security limitations. Flexible alternating current transmission system (FACTS) is a system consisting of static equipment used for transmitting electrical energy in the form of AC. The static synchronous series compensator (SSSC) is a specific form of series FACTS device. The unified power flow controller (UPFC) is a FACTS device that is connected in parallel and series with a transmission line. In this research, hybrid simulated annealing and tabu search (hybrid SATS) algorithm is designed to solve SCOPF problems that involve use of FACTS devices. The combination of simulated annealing and tabu search is intended to improve algorithm's pace of convergence and the quality of its solutions. Hybrid SATS with FACTS devices are used to investigate line flow limit violations during single line failures and ensure power flows remain within their security limitations. The efficacy of proposed algorithm is demonstrated through case studies utilizing IEEE 30 bus system. These case studies demonstrate algorithm's capabilities to achieve optimal and secure power system functioning to demonstrate its effectiveness.



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## 1. INTRODUCTION

In contemporary power system operation, achieving optimal performance while ensuring security remains a significant challenge. The security constrained optimal power flow (SCOPF) problem addresses this challenge by optimizing the power system's operation while considering security constraints under various operating conditions. With the ever-growing complexity and uncertainties in power systems, traditional optimization techniques often struggle to provide satisfactory solutions. Consequently, there is a pressing need for innovative algorithms capable of effectively addressing SCOPF problems [1]-[3]. This study introduces the hybrid simulated annealing and tabu search (hybrid SATS) algorithm for solving SCOPF problems using flexible alternating current transmission system (FACTS) devices. Static VAR compensators (SVCs) and thyristor-controlled series capacitors (TCSCs) improve power system controllability and flexibility. They improve system stability and dependability by supporting reactive power, regulating voltage, and controlling power flow [4], [5]. Due to their discontinuous and nonlinear nature, FACTS devices complicate SCOPF optimization. Traditional optimization methods like linear programming and gradient-based algorithms may struggle with this complexity. Therefore, metaheuristic algorithms, which can search complex solution spaces, may be useful for SCOPF problems [6], [7]. Tabu search (TS) and simulated annealing (SA) are popular metaheuristic methods for optimization. SA, inspired by metallurgy, searches the solution space by probabilistically accepting inferior solutions to avoid local optima. However, TS uses a memory-based search technique to avoid revisiting solutions, making solution space exploration more efficient [8], [9].

In this research, the hybrid SATS algorithm uses SA and TS to solve SCOPF problems using FACTS devices. The Hybrid SATS algorithm uses the complementing nature of these two methods to improve convergence rate and solution quality for robust and efficient power system operation under security constraints [10]. This paper proposes the Hybrid SATS method for power system optimization, which may solve SCOPF problems using FACTS devices. This research intends to promote optimal and secure power system operation by groundbreaking algorithmic design and rigorous evaluation [11], [12]. The SCOPF problem optimizes power generation and transmission while ensuring system security under diverse operational situations. Traditional linear programming or gradient-based SCOPF optimization methods may struggle to handle power system nonlinearities and discrete characteristics, especially when using FACTS devices [13]-[15]. FACTS devices are vital for power system controllability and flexibility. SVCs, TCSCs, and UPFCs provide reactive power, control power flow and regulate voltage. Power system operators can reduce line losses, voltage variations, and system instability by strategically deploying FACTS devices [16], [17].

Due to their discontinuous and nonlinear nature, FACTS devices complicate SCOPF optimization. Traditional optimization methods may struggle with these complications, resulting in inferior solutions or convergence concerns. Researchers use metaheuristic algorithms to optimize and explore difficult solution spaces [18]. GA, PSO, SA and TS can solve SCOPF problems. These algorithms escape local optima and explore diversified solution space using novel search strategies inspired by natural occurrences or human behavior. Metaheuristic algorithms can handle power system optimization's nonlinearities and discrete characteristics, making them ideal for SCOPF problems with FACTS devices [19]-[21]. A stochastic optimization approach based on metallurgy's annealing process is SA. It explores the solution space by probabilistically accepting inferior answers by simulating heating and cooling a material to a low-energy state [22]. TS, a metaheuristic method, avoids revisiting solutions by using memory-based search. TS avoid repeating cycles and optimizes solution space search by maintaining a tabu list. Metaheuristic algorithms have been applied to FACTS-based SCOPF problems in several researches. These studies show that metaheuristics can optimize and safeguard power system operation. Many algorithms use single-metaheuristic techniques or are unreliable for complex optimization tasks [23]. Given these factors, this research offers hybrid SATS algorithm for addressing SCOPF issues with FACTS devices. Hybrid SATS uses SA and TS search to use their complimentary capabilities to produce robust and economical solutions for optimal power system operation under security restrictions [24].

This research proposes merging a Hybrid SATS algorithm with FACTS devices to solve the SCOPF problem. Extensive experimentation and analysis have shown that the proposed solution improves power system efficiency, reliability, and security. The research emphasizes the importance of FACTS devices in SCOPF optimization, especially in modern power systems with complex network topologies and rising demand for secure and efficient energy transmission.

## 2. METHOD

Hybrid SATS solves the SCOPF problem with FACTS devices by combining SA and TS. A stochastic optimization approach called SA is based on metallurgical process of heating and cooling a material to a low-energy state. Accepting inferior answers with a given probability lets it explore the solution space and avoid local optima. TS, a metaheuristic algorithm, avoids revisiting solutions by using memory. By keeping a tabu list, the algorithm avoids repeating cycles [25], [26]. The hybrid SATS algorithm initializes the search and iteratively improves the solution by investigating the neighbouring solution using SA and TS. SA diversifies the search and avoids local optima, while TS guides the search to attractive solution space regions. The technique dynamically adjusts parameters like temperature schedule in SA and tabu list length in TS to balance exploration and exploitation during optimization [27].

### 2.1. Static synchronous series compensator

The static synchronous series compensator (SSSC) main component is voltage source converter, a controller that is coupled in series. The installation of SSSC in the line primarily serves to control active power flow. It controls magnitudes of the power system's bus voltages in addition to the real power. It controls the transmission line's reactance by producing and injecting a series voltage $V_{se}$ into the line. The power flow of the line is control managed by SSSC integration. The voltage source $V_{se}$ linked in series and the coupling transformer impedance $Z_{se}$ represents SSSC circuit. Here, we're assuming that bus j is where the line is connected in series via SSSC. The reactive and active power flows of SSSC branch i-j that enter bus j are identical to those of the transmission line at the sending end. Controlling the power flow of line i-j or the voltage of bus i or j is possible in actual SSSC operation by regulating $V_{se}$.

For the equivalent circuit of SSSC, suppose $V_{se}=V_{se}\angle\delta_{se}$, $V_i=V_i\angle\delta_i$, and $V_j=V_j\angle\delta_j$; then SSSC power flow constrints can be derived from the equivalent circuit as:

$$P_{ij} = V_i^2 G_{ii} - V_i V_j\left(G_{ij}\, cos\, \delta_{ij} + B_{ij}\, sin\, \delta_{ij}\right) - V_i V_{se}\left[G_{ij}\, cos(\delta_i - \delta_{se}) + B_{ij}\, sin(\delta_i - \delta_{se})\right] \quad (1)$$

$$Q_{ij} = -V_i^2 B_{ii} - V_i V_j\left(G_{ij}\, sin\, \delta_{ij} - B_{ij}\, cos\, \delta_{ij}\right) - V_i V_{se}\left[G_{ij}\, sin(\delta_i - \delta_{se}) - B_{ij}\, cos(\delta_i - \delta_{se})\right] \quad (2)$$

$$P_{ji} = V_j^2 G_{jj} - V_i V_j\left(G_{ij}\, cos\, \delta_{ji} + B_{ij}\, sin\, \delta_{ji}\right) + V_j V_{se}\left[G_{ij}\, cos(\delta_j - \delta_{se}) + B_{ij}\, sin(\delta_j - \delta_{se})\right] \quad (3)$$

$$Q_{ji} = -V_j^2 B_{jj} - V_i V_j\left(G_{ij}\, sin\, \delta_{ji} - B_{ij}\, cos\, \delta_{ji}\right) + V_j V_{se}\left[G_{ij}\, sin(\delta_j - \delta_{se}) - B_{ij}\, cos(\delta_j - \delta_{se})\right] \quad (4)$$

### 2.2. Unified power flow controller

To regulate flow of power, one uses unified power flow controller (UPFC). Two converters that rely on voltage sources as their basis make up the UPFC. The two converters share a DC connection. A series transformer couples series inverter to line. Transformer that is linked to a shunt couple to a local bus and the shunt inverter in this case. To meet operating control needs, the shunt inverter absorbs or produce reactive power that to be controlled, and it can actively interchange power with the series inverter. The UPFC impedances of the shunt and series coupling transformer are, $Z_{sh}$ and $Z_{se}$. At the receiving end line, $V_k$ is represents voltage on bus k, whereas $V_i$ and $V_j$ represent the voltages at buses i and j. Current is flowing via the shunt converter UPFC is $I_{sh}$. Active power through the shunt converter branch is denoted as $P_{sh}$, whereas reactive power is denoted as $Q_{sh}$. Both $P_{sh}$ and $Q_{sh}$ are transferring power away from bus i. $I_{ij}=-I_{ji}$, where $I_{ji}$ and $I_{ij}$ are the currents flowing through series UPFC converter. Active and reactive power from the UPFC series, $P_{ij}$ and $Q_{ij}$, respectively, as they exit $i^{th}$ bus. Active and reactive power of bus j, denoted as $P_{ji}$ and $Q_{ji}$, respectively, in the UPFC series branch. Shunt converter with link DC actual power exchange is represented as $P_{sh}$. Series converter with link DC actual power exchange is denoted as $P_{se}$. For UPFC equivalent circuit, suppose $V_{se} = V_{se}\angle\theta_{se}, V_{sh} = V_{sh}\angle\theta_{sh},$, $V_i = V_i\angle\theta_{i,} V_j = V_j\angle\theta_j$; power flow constraints of UPFC shunt and series branches:

$$P_{sh} = V_i^2 g_{sh} - V_i V_{sh}(g_{sh} \cos(\theta_i - \theta_{sh}) + b_{sh} \sin(\theta_i - \theta_{sh})) \quad (5)$$

$$Q_{sh} = -V_i^2 b_{sh} - V_i V_{sh}((g_{sh} \sin(\theta_i - \theta_{sh}) - b_{sh} \cos(\theta_i - \theta_{sh})) \quad (6)$$

$$P_{ij} = V_i^2 g_{ij} - V_i V_j\left(g_{ij} \cos\theta_{ij} + b_{ij} \sin\theta_{ij}\right) - V_i V_{se}\left(g_{ij} \cos(\theta_i - \theta_{se}) + b_{ij} \sin(\theta_i - \theta_{se})\right) \quad (7)$$

$$Q_{ij} = V_i^2 b_{ij} - V_i V_j\left(g_{ij} \sin\theta_{ij} - b_{ij} \cos\theta_{ij}\right) - V_i V_{se}\left(g_{ij} \sin(\theta_i - \theta_{se}) - b_{ij} \sin(\theta_i - \theta_{se})\right) \quad (8)$$

$$P_{ji} = V_j^2 g_{ij} - V_i V_j\left(g_{ij} \cos\theta_{ji} + b_{ij} \sin\theta_{ji}\right) + V_j V_{se}\left(g_{ij} \cos(\theta_j - \theta_{se}) + b_{ij} \sin(\theta_j - \theta_{se})\right) \quad (9)$$

$$Q_{ji} = V_j^2 b_{ij} - V_i V_j\left(g_{ij} \sin\theta_{ji} - b_{ij} \cos\theta_{ji}\right) + V_j V_{se}\left(g_{ij} \sin(\theta_j - \theta_{se}) - b_{ij} \sin(\theta_j - \theta_{se})\right) \quad (10)$$

### 2.3. Hybrid simulated annealing and tabu search algorithm

Hybrid SATS method uses SA and TS to find quickly an optimal result. SA is powerful global optimization method. SA takes a long time to compute and delays finding the best answer in a region. Thus, SA and local search are integrated. SA finds the ideal region, and local optimizer finds the optimal solution. TS is a local search heuristic. Its intrinsic adaptive memory doesn't keep to the same solutions and prevents the search from returning until the ambition requirement is met. The paper offers hybrid SATS algorithm with FACTS devices for SCOPF problems. This hybrid technique improves solutions by combining SA and TS. The trial-generated SA neighborhood solution generates TS's neighborhood. The results are promising because SA finds initial answer for good solutions, further TS takes it until meets condition for desired termination, FACTS controls the power flow in line. Briefly describe hybrid method's primary implementation steps:

- Step 1: input the system data for load flow analysis.
- Step 2: select a FACTS device and its location in the system.
- Step3: initial population of trial neighborhood solution vectors is initialized randomly by:

$$X_i = X_i^{min} + u\left(X_i^{max} - X_i^{min}\right) \quad (11)$$

- Step 4: evaluating objective function is to conduct each individual power flow study.
- Step 5: the initial solution vector is perturbed according to probability distribution function to obtain trial neighborhood solution vectors. To create a solution vector for a trial neighborhood at random, one can use:

$$S_T^{(k,m)} = S_T^{(k,0)} + (T_K \times [U] \times F_U) \quad (12)$$

$$T_k = r^{(k-1)} \times T_1 \quad (13)$$

- Step 6: the decision movement solution of current neighborhood can be designed based on acceptance criterion as tabu list:

$$P^k = \frac{1}{1+exp(\delta/T_k)} \quad (14)$$

- Step7: if the number of iterations reaches the maximum allowable number, the iteration process is terminated. Otherwise, the perturbation and acceptance criterion will be reiterated until the criterion is satisfied.

### 2.4. Mathematical formulation of OPF problem

Improving system performance while minimizing certain target functions is the goal of placing the FACTS devices. Minimizing the overall cost of generator fuel is objective function for the optimal power issue that incorporates FACTS device. This problem is written as follows:

$$J = \sum_{i=1}^{NG}(a_i + b_i P_{Gi} + c_i P_{Gi}^2) \quad (15)$$

where $i^{th}$ generator cost coefficients are $a_i$, $b_i$ and $c_i$ with units as \$/hr,\$/MW hr and \$/(MW)$^2$ hr respectively.

The equality and inequality constraints of OPF problem is as following,

$$P_{Gi} - P_{Di} = \sum_{j=1}^{NB}|V_i|\,|V_j||Y_{ij}|\,cos(\,\theta_{ij} - \delta_i + \delta_j) \quad (16)$$

$$Q_{Gi} - Q_{Di} = -\sum_{j=1}^{NB}|V_i||V_j||Y_{ij}|\,sin(\,\theta_{ij} - \delta_i + \delta_j) \quad (17)$$

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max} \qquad i \in \text{NG} \quad (18)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \qquad i \in \text{NG} \quad (19)$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \qquad i \in \text{NG} \quad (20)$$

$$T_i^{min} \le T_i \le T_i^{max} \qquad i \in \text{NT} \quad (21)$$

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max} \qquad i \in \text{NLB} \quad (22)$$

$$S_{Li} \le S_{Li}^{max} \; i \in \text{NL} \quad (23)$$

FACTS devices:
SSSC series voltage source angle and magnitude limits constraints:

$$V_{se}^{min} \le V_{se} \le V_{se}^{max} \quad (24)$$

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \quad (25)$$

UPFC series and shunt voltage source magnitude and angle limits constraints, respectively.

$$V_{se}^{min} \leq V_{se} \leq V_{se}^{max} \quad (26)$$

$$\theta_{se}^{min} \leq \theta_{se} \leq \theta_{se}^{max} \quad (27)$$

## 3. RESULTS AND DISCUSSION

The suggested hybrid SATS algorithm with FACTS devices is tested on standard IEEE 30 bus for solving SCOPF problem and executed by using MATLAB. Six generators, forty-one transmission lines, and four transformers with tap changing structure IEEE 30 bus. As a set of control variables following are taken the active power outputs, terminal voltages, and tap settings of the generator and transformer. At 1.05 p.u., voltage magnitude for the slack bus cannot go higher. For every other generator buss, the voltage magnitude restrictions are 0.95 p.u. at bottom and 1.1 p.u. at top. There is a voltage magnitude restriction of 0.9 p.u. for all taps of transformer and an upper limit of 1.1 p.u. Two cases taken to show how well the suggested hybrid SATS algorithm works with the FACTS device in simulation studies:

- Case (a): a single SSSC series FACTS device is set up on the line that connects busses 6 and 7. With real and reactive power values 0.4 and 0.01 for the SSSC, respectively.
- Case (b): a single UPFC shunt-series device is set up on the line that connects busses 6 and 7, with the following real and reactive power parameters: $P_{mk}$=0.45 and $Q_{mk}$=0.3.

We used a combination of literature reviews and trial and error to determine the best place to implant the FACTS device. In addition, the base case and contingency conditions are used to examine cases (a) and (b). The parameters considerd are an initial temperature of 1,000 C, a reduction rate of 0.95, 50 trial solutions, and a size of tabu list of 10.

### 3.1. Base case condition

The suggested hybrid SATS with FACTS device is utilized to govern optimal scheduling of the power system under base case conditions. Minimization of the cost of fuel is objective function for the generator. The table labeled as Table 1 presents the best settings for the control variables in the base case scenario, which were determined using the hybrid SATS approach with the inclusion of SSSC and UPFC. The hybrid SATS with UPFC approach achieves a minimum generator fuel cost of 807.34 $/hr, which is lower than the hybrid SATS with SSSC method. In hybrid SATS, the UPFC approach requires less processing time to obtain the optimal solution compared to the SSSC method. Furthermore, it has been determined that all of the solutions produced adhere to the restrictions imposed on the limits of control variables and the line flow.

Table 1. Hybrid SATS with SSSC and UPFC optimal control variables for base case condition

| Control Variables | | hybrid SATS with SSSC | hybrid SATS with UPFC |
|---|---|---|---|
| $P_G\,(MW)$ | $P_{G1}$ | 160.33 | 171.62 |
| | $P_{G2}$ | 25.77 | 47.49 |
| | $P_{G5}$ | 20.71 | 20.92 |
| | $P_{G8}$ | 34.63 | 19.67 |
| | $P_{G11}$ | 20.41 | 20.57 |
| | $P_{G13}$ | 29.74 | 13.05 |
| $V$ (p.u.) | $V_1$ | 1.0500 | 1.0632 |
| | $V_2$ | 1.0315 | 1.0436 |
| | $V_5$ | 1.0092 | 1.0143 |
| | $V_8$ | 1.0221 | 1.0103 |
| | $V_{11}$ | 1.0481 | 0.9619 |
| | $V_{13}$ | 0.9935 | 1.0320 |
| Tap (p.u.) | $T_{6,9}$ | 1.0159 | 0.9727 |
| | $T_{6,10}$ | 1.0595 | 0.9244 |
| | $T_{4,12}$ | 1.0477 | 0.9517 |
| | $T_{28,27}$ | 0.9471 | 0.9398 |
| Cost ($/hr) | | 826.81 | 807.34 |
| Loss (MW) | | 8.19 | 9.91 |

### 3.2. Contingency condition

According to the contingency analysis the top three contingencies are line outages 2-5, 4-6, and 3-4 which caused a substantial overload on the other line. Table 2 provides a summary of the overloaded lines. The reliability of the electricity grid is affected by potential contingency situations. The line outages 2-5, 4-6, and 3-4 are taken into account for security assessment in this research effort. The suggested approach can alleviate overloaded lines under less severe contingency if it alleviates line overload under the most severe contingency.

Table 2. Summary of overloaded lines of top three contingencies for IEEE 30 bus

| Line outage | Overloaded lines | Line flow limit (MVA) | Line flow (MVA) |
|---|---|---|---|
| 2-5 | 2-6 | 65 | 75.83 |
| | 5-7 | 70 | 81.77 |
| 4-6 | 1-2 | 130 | 132.89 |
| | 2-6 | 65 | 71.91 |
| 3-4 | 1-2 | 130 | 181.08 |

To evaluate effectiveness of suggested hybrid SATS with FACTS device in solving SCOPF problem, it is implemented in three specific network contingencies that are considered to be the most severe. The objective function is to optimize power system security while minimizing the cost of generator fuel. Table 3 displays the ideal control variable settings for three selected network contingency using the hybrid SATS approach with SSSC and UPFC. The table labeled as Table 4 provides a summary of the line flow for overloaded lines in three selected network situations. This information is obtained using the hybrid SATS approach with SSSC and UPFC. Figures 1 to 3 demonstrate the percentage line loadings for three specific network contingencies using the hybrid SATS approach with SSSC and UPFC, respectively.

Table 3. Optimal control variables settings under the selected three network contingencies using hybrid SATS method with SSSC and UPFC

| Control Variables | | Line 2-5 outage | | Line 4-6 outage | | Line 3-4 outage | |
|---|---|---|---|---|---|---|---|
| | | SSSC | UPFC | SSSC | UPFC | SSSC | UPFC |
| $P_G\,(MW)$ | $P_{G1}$ | 120.69 | 155.24 | 118.52 | 164.21 | 119.27 | 132.14 |
| | $P_{G2}$ | 57.76 | 42.65 | 57.76 | 45.96 | 57.76 | 60.04 |
| | $P_{G5}$ | 24.68 | 40.90 | 24.68 | 23.94 | 24.68 | 24.82 |
| | $P_{G8}$ | 29.34 | 13.57 | 29.34 | 28.58 | 29.34 | 35.00 |
| | $P_{G11}$ | 27.11 | 30.00 | 27.11 | 18.65 | 27.11 | 16.96 |
| | $P_{G13}$ | 36.18 | 12.00 | 36.18 | 12.00 | 36.18 | 23.29 |
| *V (p.u.)* | $V_1$ | 1.0500 | 1.0660 | 1.0500 | 1.0748 | 1.0500 | 1.0500 |
| | $V_2$ | 1.0798 | 1.0513 | 1.0798 | 1.0501 | 1.0798 | 1.0303 |
| | $V_5$ | 0.9500 | 1.0136 | 0.9500 | 1.0153 | 0.9500 | 1.0260 |
| | $V_8$ | 1.0165 | 1.0112 | 1.0165 | 1.0194 | 1.0165 | 1.0016 |
| | $V_{11}$ | 1.1000 | 0.9973 | 1.1000 | 1.1000 | 1.1000 | 1.0146 |
| | $V_{13}$ | 0.9500 | 1.0616 | 0.9500 | 1.0435 | 0.9500 | 1.0031 |
| *Tap (p.u.)* | $T_{6,9}$ | 1.1000 | 0.9226 | 1.1000 | 0.9558 | 1.1000 | 0.9961 |
| | $T_{6,10}$ | 1.1000 | 0.9576 | 1.1000 | 1.0413 | 1.1000 | 0.9831 |
| | $T_{4,12}$ | 1.0964 | 0.9519 | 1.0964 | 0.9548 | 1.0964 | 0.9888 |
| | $T_{28,27}$ | 0.9680 | 0.9329 | 0.9680 | 0.9609 | 0.9680 | 0.9573 |
| Cost ($/hr) | | 861.67 | 850.50 | 855.41 | 810.65 | 857.57 | 826.71 |
| Loss (MW) | | 12.35 | 10.96 | 10.19 | 9.94 | 10.94 | 8.85 |

Table 4. Summary of overloaded lines under selected three network contingencies by hybrid SATS method with SSSC and UPFC

| Line outage | Overloaded lines | Line flow limit (MVA) | Line flow (MVA) | | Cost ($/hr) | | Loss (MW) | |
|---|---|---|---|---|---|---|---|---|
| | | | SSSC | UPFC | SSSC | UPFC | SSSC | UPFC |
| 2-5 | 2-6 | 65 | 60.84 | 59.17 | 861.6 | 850.5 | 12.35 | 10.96 |
| | 5-7 | 70 | 69.88 | 54.28 | | | | |
| 4-6 | 1-2 | 130 | 123.23 | 119.60 | 855.4 | 810.6 | 10.1 | 9.94 |
| | 2-6 | 65 | 59.34 | 55.93 | | | | |
| 3-4 | 1-2 | 130 | 128.13 | 128.71 | 857.5 | 826.7 | 10.9 | 8.8 |

Tables 3 and 4 show that the hybrid SATS with UPFC technique achieves a lower minimum fuel cost competed to the hybrid SATS with SSSC method. Furthermore, it is evident that the hybrid SATS approach with SSSC and UPFC effectively mitigates the overload on the lines for the three specified network contingencies. In hybrid SATS, the UPFC approach requires less processing time to generate the optimal solution compared to the SSSC method. Therefore, the hybrid SATS with UPFC approach yields improved and satisfactory outcomes. This demonstrates the efficacy of the hybrid SATS with UPFC technique in resolving the SCOPF problem by getting desired objective while adhering to limits on control variables and line flow. Research has demonstrated that implementing hybrid SATS with the UPFC approach can significantly improve power system security during contingency situations.

This research introduces the Hybrid SATS algorithm with FACTS devices is a innovative solution to SCOPF problem. The program successfully improves convergence rates and solution quality by utilizing SA and SA approaches. This leads to enhanced power system security and minimized generator fuel costs. The efficacy of suggested method is proved by directing thorough case studies on standard IEEE 30 bus system. These studies highlight potential of the plan to enhance power system operations and maintain security limitations.

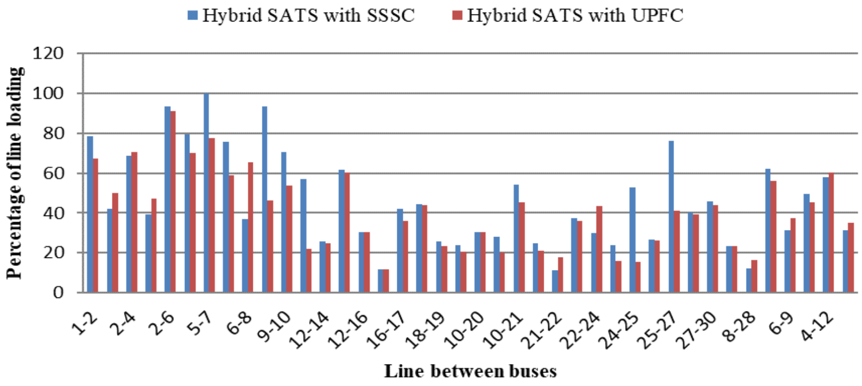


Figure 1. Line loadings under line 2-5 outage using hybrid SATS method with SSSC and UPFC

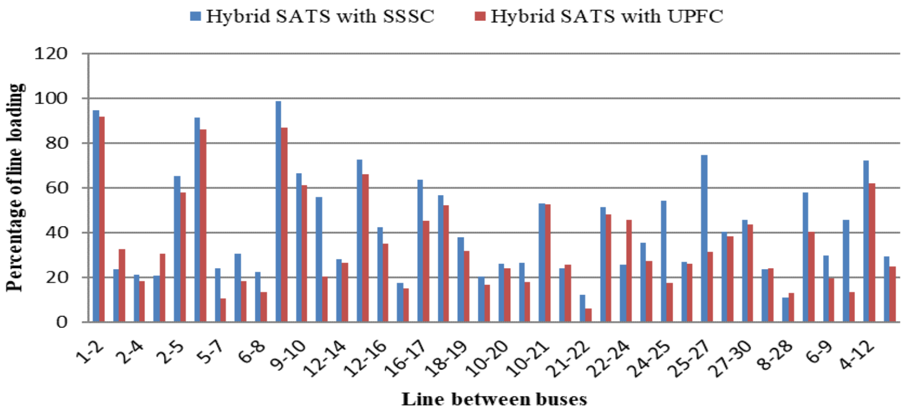


Figure 2. Line loadings under line 4-6 outage using hybrid SATS method with SSSC and UPFC

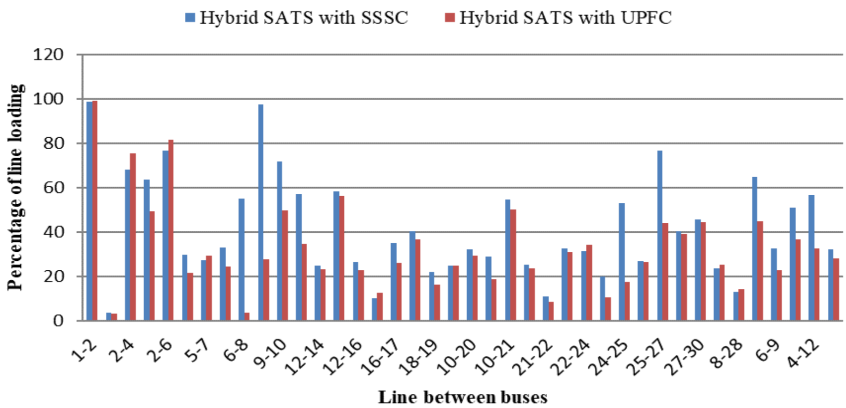


Figure 3. Line loadings under line 3-4 outage using hybrid SATS method with SSSC and UPFC

## 4. CONCLUSION

This research presents the utilization of hybrid SATS with FACTS devices, specifically SSSC and UPFC, to address the security constrained optimal power flow problem. The research focuses on three critical network contingencies. This algorithm integrates SA and TS techniques to efficiently obtain an optimal solution within a limited timeframe. The efficiency of the suggested hybrid technique with FACTS device is demonstrated by simulation results obtained on the IEEE 30 bus system. The proposed method using the FACTS device consistently achieved the optimal solution by meeting stated objective and satisfying constraints on control variables and line flow limit. The test findings indicate that the hybrid SATS with UPFC approach is significantly more effective than the hybrid SATS with SSSC in achieving defined objective and enhancing power system security during contingency situations. This work can be implemented into a high-capacity system to progress power transfer capabilities and enhance the power system quality.

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