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# Application of Metaheuristic Algorithms for Optimal Power Flow Solutions with SSSC Device

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**Abstract:** -The optimal power flow problem is an optimization tool that applied for obtaining the best operating point (control variables) for given objective functions with satisfying the system equality and inequality constraints. The Flexible Alternating Current Transmission Systems devices have been widely used in electrical power systems networks connected on the transmission line or the bus. Hence, the SSSC controller is a useful FACTS device based on voltage source converter. It can inject a controllable voltage within the given limits in series with a transmission line to control the active and reactive power flow through the transmission line. In this paper, the optimal power flow solution without and with SSSC FACTS device was discussed. The algorithm to solve the OPF problems is proposed Multi Population-based Modified Jaya (MPMJ) algorithm and compared with TLBO and JAYA algorithms. The optimal location of the SSSC device is determined using the Analytical Hierarchy Process (AHP) method. Therefore, the proposed MPMJ optimization algorithm applied with SSSC device for optimal values of total fuel cost of generation, real power loss, the total voltage deviation, and the sum of squared voltage stability index on the standard IEEE-57 bus test systems. The results obtained by the proposed MPMJ algorithm are better solutions effectively in the presence of the SSSC device than the recent algorithm reported in the literature.

**Index terms**: -Analytical Hierarchy Process, Fuel cost of generation, Multi-Population based Modified Jaya algorithm, Optimal power flows

## 1. Introduction

The electric power system classified power generating stations, transmission & distribution systems, and substations with transformers & circuit breakers. The electrical system is complicated and spread over large geographical areas. The transmission line connects the generation station with substation or connecting substation to concerned loads, which is the central part of power system components. Figure 1 shows the power system components structure from the generation station to the load through the transmission line and compensating FACTS device.

The generating station consists of the prime mover, generator, and energy sources. The prime mover includes gas turbines, steam engines, etc. The energy sources may consist of coal, the oil burned in the furnace to heat water, steam in the boiler, hydropower, geothermal, solar energy, wind energy, etc. The transmission line is connecting between the generating station to the substation through the transformer and FACTS devices. A distribution system connects all the individual loads in a specified area to the transmission lines, through transformers and load wires.

FACTS devices work by supplying or absorbing reactive power, increasing or decreasing voltage, and regulating series impedance of transmission lines or phase angle [1]. On the other hand, FACTS devices represent a useful device used to improve the overall power system network performances by controlling power flow through transmission lines and voltage profile. These devices are introduced in the OPF problem for various objectives, such as reducing total fuel cost, active power loss, the sum of voltage deviation, and enhancing the voltage stability index [1].

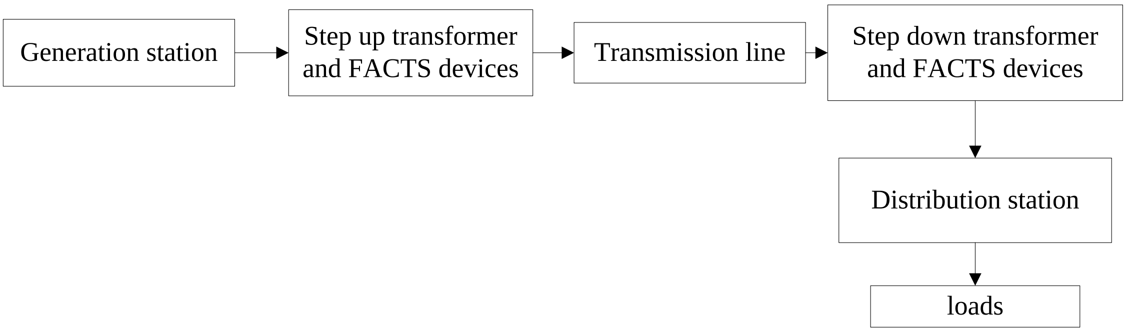

Figure 1. Electrical power system structures

In this paper, metaheuristic TLBO, JAYA, and proposed MPMJ algorithm-based optimization techniques without and with SSSC device are applied to the IEEE-57 bus test system and compared its performance to minimize total fuel cost of the generation, total active power loss, voltage deviation, and the sum of squared voltage stability index.

## 2. SSSC FACTS device

The series SSSC FACTS device can monitor power flow and boost system performance. SSSC may also have either capacitive injected voltage or inductive injected voltage for compensation. Sensitivity-based approach, artificial intelligence approaches, point-of-voltage collapse process, nodal analysis, frequency response, stability index, and control theories are methods of locating the SSSC device based on several parameters [3],[4].

## 3. Modelling of Static Synchronous Series Compensator (SSSC)Device

Over the past two decades, research has centred on developing modelling FACTS instruments for steady-state and transient power system analysis. Depending on the type of study required, FACTS devices' effect was integrated into power system analysis with various mathematical models. Power injection model is an excellent controller for steady-state power flow analysis, as it manages them well in load flow computation. Because power injection models do not disrupt the current bus admission matrix, it can easily be integrated into the Newton Raphson load flow program [5]. The SSSC injects a voltage (Vs) in series to the system where it is installed, and the maximum SSSC voltage is 0.1pu, and its phase angle can vary from 0 to 180 degrees [2],[6]. Modelling of SSSC for OPF application is shown in Figure 2. The SSSC device is located in series with the transmission line, and its equivalent circuit is given Figure 3.

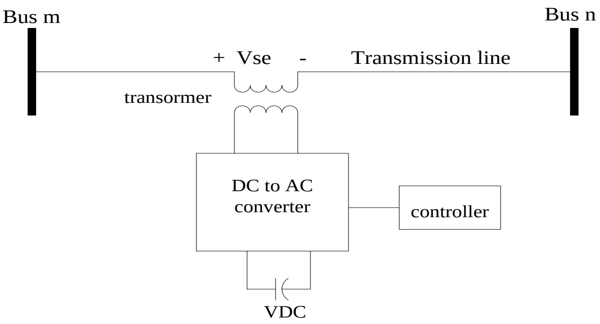

Figure 2. Schematic diagram of SSSC device to locating in between transmission line

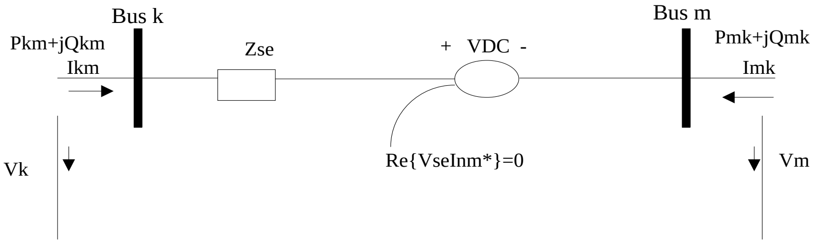

Figure 3. Equivalent circuit of SSSC device

The equivalent circuit of SSSC is as shown in Figure 3. From the equivalent circuit, the power flow constraints of the SSSC can be given as

$$\begin{aligned} P_{km} &= V_k^2 g_{kk} - V_k V_m (g_{km} \cos\theta_{km} + b_{km} \sin\theta_{km}) - V_k V_{se} (g_{km} \cos(\theta_k - \theta_{se}) \\ &\quad + b_{km} \sin(\theta_k - \theta_{se})) \end{aligned} \tag{1}$$

$$\begin{aligned} Q_{km} &= -V_k^2 b_{kk} - V_k V_m (g_{km} \sin\theta_{km} - b_{km} \cos\theta_{km}) - V_k V_{se} (g_{km} \sin(\theta_k - \theta_{se}) \\ &\quad - b_{km} \cos(\theta_k - \theta_{se})) \end{aligned} \tag{2}$$

$$\begin{aligned} P_{mk} &= V_m^2 g_{mk} - V_k V_m (g_{km} \cos\theta_{mk} + b_{km} \sin\theta_{mk}) + V_m V_{se} (g_{km} \cos(\theta_m - \theta_{se}) \\ &\quad + b_{km} \sin(\theta_m - \theta_{se})) \end{aligned} \tag{3}$$

$$\begin{aligned} Q_{mk} &= -V_m^2 b_{mm} - V_k V_m (g_{km} \sin\theta_{mk} - b_{km} \cos\theta_{mk}) + V_m V_{se} (g_{km} \sin(\theta_m - \theta_{se}) \\ &\quad - b_{km} \cos(\theta_m - \theta_{se})) \end{aligned} \tag{4}$$

where $g_{km} + mb_{km} = 1/Z_{se}, g_{kk} = g_{km}, b_{kk} = b_{km}, g_{mm} = g_{km}, b_{mm} = b_{km}$

Operating constraint of the SSSC (active power exchange via the DC link) is as

$$\begin{aligned} &PE = \mathrm{Re}(V_{se} I_{mk}^{*}) = 0 \quad or \\ &PE = -V_k V_{se} (g_{km} \cos(\theta_k - \theta_{se}) - b_{km} \sin(\theta_k - \theta_{se})) \\ &+ V_m V_{se} (g_{km} \cos(\theta_m - \theta_{se}) - b_{km} \sin(\theta_m - \theta_{se})) = 0 \end{aligned} \tag{5}$$

The active power flow constraint is

$$P_{mk} - P_{mk}^{specified} = 0 \tag{6}$$

$$Q_{mk} - Q_{mk}^{specified} = 0 \tag{7}$$

Where $P_{mk}^{specified}$ is specified active power flow.

The equivalent voltage injection $V_{se} \angle \theta_{se}$ bound constraints are:

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \tag{8}$$

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \tag{9}$$

## 4. Mathematical formulations of optimal power flow

The mathematical formulations of optimal power flow problems for the considered objective function are discussed in the following equations.

$$f_1 = F(P_G) = \sum_{i=1}^{NG} (a_i P^2{}_{gi} + b_i P_{gi} + c_i) \$ / h \tag{10}$$

Where $a_i$, $b_i$ and $c_i$ are the fuel cost functions in the i$^{th}$ generator.

The sum of total power loss in the transmission line can be described as:

$$f_2 = P_{loss(i)} = \sum_{\substack{j=1 \\ i \neq j}}^{nl} g_{i,j} (V_i^2 + V_j^2 - 2V_i.V_j \cos(\delta_i - \delta_j)) \tag{11}$$

Where $nl$ a number of the transmission line, $g_{i,j}$ the conductance of the transmission line, $V_i \& V_j$ is the voltage magnitude at the given bus

The sum of voltage deviation on the bus can be described as:

$$f_3 = (VD) = \sum_{i=1}^{NL} \left( |V_i - 1| \right)^2 \tag{12}$$

The sum of the squared voltage stability index (L) at the load bus stated as:

$$f_4 = L_j = \left| 1 - \sum_{i=1}^{ng} F_{ji} \frac{V_i}{V_j} \angle \theta_{ij} + \delta_i - \delta_j \right| \tag{13}$$

Where $\theta_{ij}$ is the power factor angle and $\delta_i \& \delta_j$ are voltage angle of the i$^{th}$ and j$^{th}$ bus respectively

### *Equality Constraints*

The equality constraints of the OPF reflect the physics of the power system. The typical power flow equations represent the physics of the power system. These equality constraints are as follows.

a) Real power constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \cos\left( \theta_{ij} - \delta_i + \delta_j \right) = 0 \tag{14}$$

b) Reactive power constraints

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i| |V_j| |Y_{ij}| \sin\left( \theta_{ij} - \delta_i + \delta_j \right) = 0 \tag{15}$$

Where $j \in [1, n]$ and, n=number of bus

### *Inequality Constraints*

The inequality constraints of the OPF reflect the limits on physical devices present in the power system and the limitations created to guarantee system security. These inequality constraints are as follows.

a) Generator constraints

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}\text{, i=1…NG}\; V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max}\text{,i=1…NG} \qquad (16)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}\text{,i=1…NG}$$

b) Transformer constraints

Transformer tap settings ought to be restricted within their specified lower and upper limits as follows:

$$T_i^{\min} \le T_i \le T_i^{\max}\text{, i=1…NT} \qquad (17)$$

c) Shunt Var compensator constraints

Shunt VAR compensators must be restricted by their lower and upper limits as follows:

$$Q_{Ci}^{\min} \le Q_{GCi} \le Q_{Ci}^{\max}\text{,i=1…NG} \qquad (18)$$

d) Security constraints

$$V_{Li}^{\min} \le V_{Li} \le V_{Li}^{\max}\text{,i=1…NL} \qquad (19)$$

$$S_{li} \le S_{li}^{\max}\text{,i=1…nl}$$

e) SSSC FACTS device constraints

SSSC voltage magnitude $V_{vR}^{\min} \le V_{vR} \le V_{vR}^{\max}$ (20)

SSSC voltage angle $\delta_{vR}^{\min} \le \delta_{vR} \le \delta_{vR}^{\max}$

## 5. Proposed Multi Population-Based Modified Jaya (MMPJ) Algorithm

The JAYA algorithm is the most powerful metaheuristic optimization algorithm for solving non-linear equations [8],[9]. Therefore, in this paper, the Multi Population-based Modified Jaya (MPMJ) algorithm was applied for the known objective function with the SSSC device. The modified Jaya algorithm mathematical equation is shown in equation (21).

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i}[(X_{j,worst,i}) - (\left|X_{j,k,i}\right|)] - L * r_{2,j,i}[(\left|X_{j,k,i}\right|^2) - (X_{j,best,i})] \qquad (21)$$

Figure 4, shows the application of the Multi-Population based Modified Jaya (MPMJ) algorithm for the solution of optimal power flow without and with SSSC device. The combination of basic multi-population flow charts included in Figure 4 for control the divergence solution by dividing the total population to subpopulation in the computation of optimal power flow problem solution for all objective function without and with SSSC device.

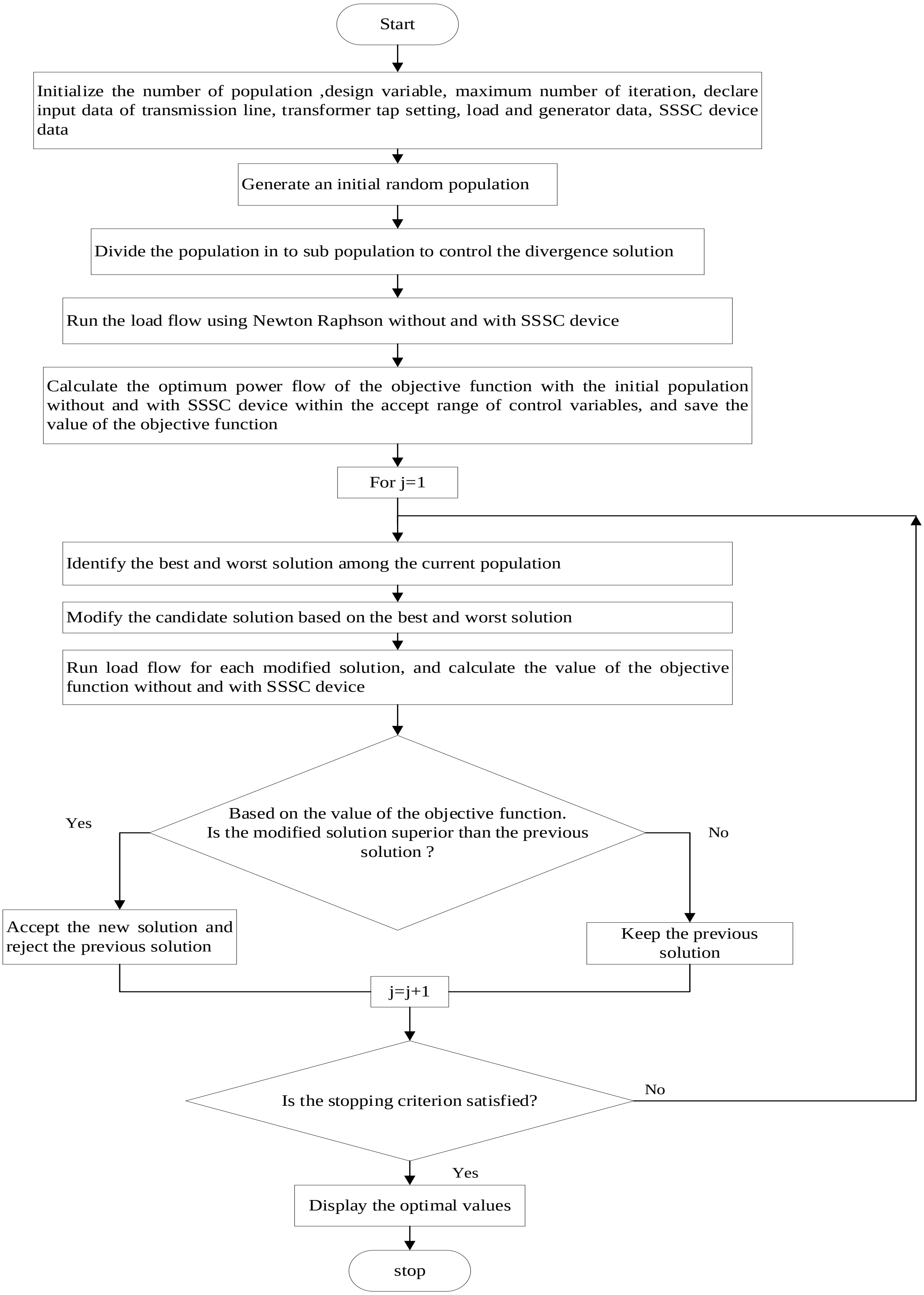

Figure 4. Flow chart of MPMJ algorithm for the application of optimum power flow solution without and with SSSC device

## 6. Implementation steps of the proposed MPMJ algorithm to OPF without and with SSSC device:

Step 1: Initialize the number of population and design variable

Step 2: Declaration of data

Step 3: Initialization

Generation count set to, iter=0, Initialize a set of random values for real power generation, generator voltages, transformer tap settings, and reactive power injections of population NP within acceptable range using the equation below:

$$P_{G,0} = rand(0,1).(P_{Gi}^{\max} - P_{Gi}^{\min}) + P_{Gi}^{\min}, \quad P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1,\ldots,ng$$

$$V_{G,0} = rand(0,1).(V_{i}^{\max} - V_{i}^{\min}) + V_{i}^{\min}, \quad V_{i}^{\min} \le V_{i} \le V_{i}^{\max}, i = 1,\ldots,ng$$

$$T_{G,0} = rand(0,1).(T_{i}^{\max} - T_{i}^{\min}) + T_{i}^{\min}, \quad T_{i}^{\min} \le T_{i} \le T_{i}^{\max}, i = 1,\ldots,nt$$

$$Q_{G,0} = rand(0,1).(Q_{i}^{\max} - Q_{i}^{\min}) + Q_{i}^{\min}, \quad Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, i = 1,\ldots,cs$$

$$X_0 = [P_{G,0}, V_{G,0}, T_{G,0}, Q_{G,0}].$$

Step 4**:** Run the Newton-Rapson load flow without and with SSSC device with this initial population to check the feasibility of the solution and satisfaction of equality an inequality constraint.

Step 5: Locate the SSSC device on the weakest bus. The weakest bus is determined using the voltage stability index. The value of the voltage stability index approach to one or beyond one becomes a weak bus. Similarly, as the bus stability index is near to zero, the system becomes stable, and no need for compensation.

Step 6: Define the objective function to be optimized individually, given below. The objective functions are fuel cost of generation, total real power loss, voltage stability index, and voltage deviation. Initialize the number of control variables and population size, the maximum number of iterations, and the maximum and minimum limits of control variables.

$$f_1 = F(P_G) = \sum_{i=1}^{ng} \left( a_i P_{Gi}^2 + b_i P_{Gi} + c_i \right),$$

$$f_2 = P_L = \sum_{i=1}^{N_l} g_k \left[ V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j) \right]$$

$$f_3 = \text{VD} = \sum_{i=1}^{NL} \left( |V_i - 1| \right)^2$$

$$f_4 = L_j = \left| 1 - \sum_{i=1}^{ng} F_{ji} \frac{V_i}{V_j} \angle \theta_{ij} + \delta_i - \delta_j \right|$$

Step 7: Run the power flow program for each candidate solution without and with the SSSC device for all objective functions.

Step 8: Identify the best and worst solutions among the candidate solutions.

Step 9: Based on the value of best and worst conditions, modify all the candidate solutions, the proposed multi population-based modified Jaya algorithm modifications expressed using equation (21). Divide the population into subpopulation, compare the new solution with the old solution for each subpopulation, and finally identify the best and discarded the worst solution.

Step 10: For all updated solutions, if any control variable is beyond the limits, replace the values within the maximum or minimum limits.

Step 11: Run the Newton-Raphson load flow method without and with the SSSC device with these modified control variables to check the feasibility of the solution and satisfaction of equality and inequality constraints. Calculate the objective function values and add the penalty functions to the objective function if the limit's volitation.

Step 12: For each solution, compare the objective function from the previous values and the updated solution. Accept the updated solution is that the values are better than the previous values. Otherwise, keep the previous solution

Step 13: The program terminates if the termination criterion is achieved, else the program continues from step 8.

## 7. Results and Discussion

The effectiveness of the metaheuristic algorithm TLBO, JAYA, and proposed Multi population Modified-based Jaya (MPMJ) algorithm without, and with SSSC device examined on IEEE-57 bus system to test the system for OPF problems. The optimal location of the SSSC device is by using Analytical Hierarchy Process (AHP) method. The proposed technique has been applied to solve the OPF problem without using the SSSC FACTS device to optimize four different objective functions.

### 7.1. Case I: Single-objective optimization without SSSC device

Figures 6(a)-6(d) shows variations in the generators total fuel cost, active power losses, bus voltage variance, reactive power loss, and voltage stability index for the original power system without connecting any SSSC device to the IEEE-57 bus system.

It is observed from Figure 6(a) that the convergence of fuel cost of generation of the IEEE 57-bus test system under normal operating conditions. The minimum costs obtained using TLB, JAYA, and proposed MPMJ algorithms are 41622$/hr, 41619$/hr, and 41614$/hr, respectively. Figure 6(b) illustrates the convergence of total real power loss of the IEEE 57-bus system under normal operating conditions. The minimum power losses obtained using TLBO, JAYA, and proposed MPMJ algorithms are 0.1502p.u, 0.1481pu and 0.148pu respectively. Figure 6(c) shows the convergence of the sum of voltage deviation of the IEEE 57-bus system under normal operating conditions. The minimum total voltage deviation obtained using TLBO, JAYA, and proposed MPMJ algorithms are 1.0111p.u, 0.856pu and 0.7011pu respectively. Figure 6(d) shows the convergence of the sum of squared voltage stability index objective function of the IEEE 57-bus system under normal operating conditions. The minimum sum of squared voltage stability index objective functions obtained using TLBO, JAYA, and proposed MPMJ algorithms are 0.2651, 0.2578 and 0.2463, respectively. Figure 6(a)-6(d) shows that the proposed MPMJ algorithm reaches the best solution within a few iterations under all objective functions of the IEEE 57-bus system without SSSC device.

### 7.2. Case II: Single-objective optimization with SSSC device at the selected locations

The proposed MPMJ algorithm is applied for solving the optimal power flow problems subjected to different equality and inequality constraints with the location of the SSSC device in the selected buses under normal operating conditions. The selected locations of SSSC are the lines 9-13,9-12,56-41,9-10, and 54-55. These locations are taken based on the first five maximum voltage stability index of the lines from the transmission line's steady-state values. The value of the voltage stability index at lines 9-13,9-12,56-41,9-10, and 54-55 is 0.1747, 0.1667, 0.1652, 0.1649, and 0.1402 respectively. In Figure 5, the line stability index for all the transmission line is displayed.

Table 1 gives the total fuel cost of generation, total real power loss, voltage stability index, and the sum of voltage deviation with the SSSC device at the selected locations for IEEE-57 bus. Table 1 shows that each candidate bus has given minimum attributes (objective function value) as the best value than optimization without the SSSC device. Also, from Table 1, it can be observed that under normal conditions, the optimal value for the cost of generation is 41608$/hr at line 54-55 the optimal value for power loss is 0.1340pu at line 9-10, the optimal value for voltage stability index is 0.235 at line 9-13, an optimal value for total voltage deviation is 0.610pu at line 9-12. With this, one can say that under normal conditions, optimal values of four attributes are obtained at different alternatives. Therefore, it is tough to differentiate the best option from considered five alternatives that operate the power transmission system more effectively and efficiently. It is also clear that considering a specific objective function in the OPF problem cannot obtain a solution that satisfies other objective functions. Hence, for achieving a result that meets some objectives, it is necessary to use the Analytical Hierarchy Process method. Thus, after solving the OPF problem for different alternatives of the objective functions/attributes, these values are given as input to AHP methods to select the best location for SSSC installation in the IEEE 57-bus test system.

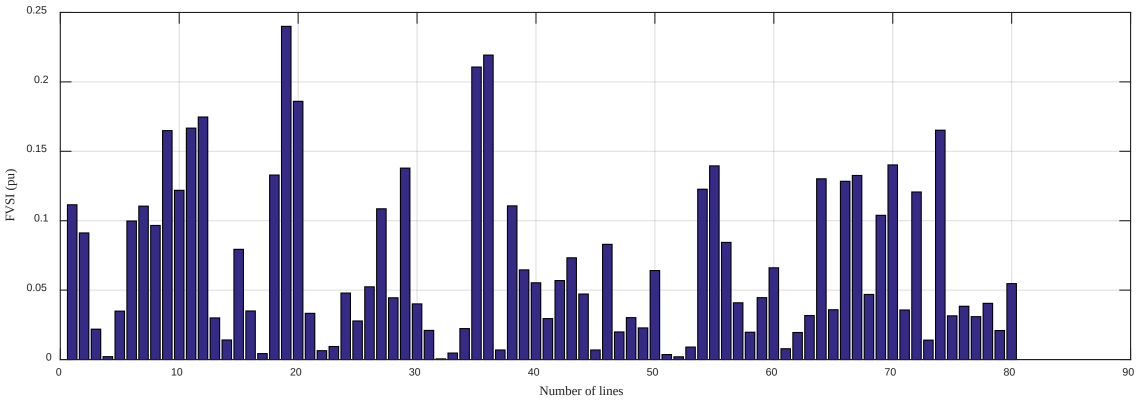

Figure 5. Line stability index for the IEEE-57 bus system

### 7.3. Case III: Application of AHP methods for determination of the optimal location of SSSC for IEEE-57 bus

AHP method is applied to differentiate the best alternative out of five considered alternatives. The optimal power flow solution is displayed in Table 1 for five weakest lines using the proposed MPMJ algorithm, as compared in Table 5 with the TLBO and JAYA algorithm. The proposed MPMJ algorithm-based result is the most optimal. The OPF results with the SSSC device are shown in Table 1, used as a decision matrix for the system and then given as an input to the AHP method. From Table 1, one or two alternatives give the best value when compared to optimization with SSSC located at other options. It is challenging to differentiate the best option from considered five alternatives that operate the power transmission system more effectively and efficiently. It is also clear that considering a specific objective function in the OPF problem cannot obtain a solution that satisfies other objective functions. Hence, for achieving a result that meets some objectives, it is necessary to use Analytical Hierarchy Process method.

The pairwise comparison matrix given in Table 2 determines the preference of each attribute over another. In pairwise comparison Table 2, diagonal elements are taken as 1, which means objectives are of equal importance. The upper diagonal elements of the matrix have been taken by giving preferences to the attributes, and the lower diagonal elements of the matrix have been taken as a reciprocal of the upper diagonal elements of the matrix. In upper diagonal elements of the matrix, the first-row second column is taken as 2, which means that the cost attribute is the intermediate values of the power loss attribute. The first row third and fourth columns are taken as 3 that means that cost attribute is slightly more important than values of the sum of squared voltage stability index and total voltage deviation attributes.

Similarly, the second-row third column is taken as 2, which means the power loss attributes the sum of squared voltage stability index intermediate values. The second-row fourth column is taken as 5, which means the power loss attribute is more important than values of the total voltage deviation attribute. Finally, the third-row fourth column is taken as 2 mean the voltage stability index value is the intermediate of voltage deviation.

Table 3 is the weight matrix of the attributes. Table 3 is a normalized principal eigenvector called a priority vector or weight matrix of the attributes. Since it is normalized, the sum of all attributes in the priority vector is 1, and the Priority vector shows relative weights among the things that we compare. From the Table 4, it is observed that 39.05% percentage of priority is given to the cost attribute, 27.61% percent priority is given to the power loss attribute, 19.53% percent priority is given to the voltage stability index, and 13.81% is given to the sum of voltage deviation attributes. The total fuel cost of generation is the most important criterion or attribute. The second most important criterion is the total real power loss. The third most important criterion is the voltage stability index and the least importance given to the voltage deviation attribute. This weight matrix or eigenvector determines the relative ranking of alternatives under each criterion. The consistency ratio is 0.0454, which is shown within the acceptable limits. The standard acceptable limit is less than 10% [10].

Table 4 shows the relative ranking of alternatives under five objective functions: the minimization of fuel cost of the generator, minimizing the total voltage deviation, minimizing active power loss, and enhancing the voltage stability index by the AHP method.  Therefore, from this, one can say that the AHP method under normal operating condition gives rank one to the alternative line 54-55 for the SSSC location to the IEEE-57 bus system. So, it is considered an optimal location for SSSC device among the lines considered for the system, which gives the highest benefits to the power system operation in terms of performance parameters.

From Table 5, under normal load case, it is clear that the control settings are corresponding to the OPF with cost minimization with the SSSC device at line 54-55. The optimized fuel cost value using TLBO, JAYA, and proposed MPMJ algorithm is 41617$/h, 41615$/h, and 41608$/h, respectively. The total active power loss enhancement from 0.1448pu by TLBO to 0.1352pu by JAYA, and 0.1341pu by proposed MPMJ algorithm. The sum of voltage deviation improved 0.922pu by TLBO to 0.750pu by JAYA, and 0.612pu by proposed MPMJ algorithm. Similarly, the minimum sum of squared voltage stability index is enhanced from 0.259 by TLBO to 0.255 by JAYA, and 0.2362 by proposed MPMJ algorithm. The convergence characteristic of each objective function with SSSC at line 54-55 is shown in Figures 7(a)-7(d), which shows smooth convergence to the optimum value without any abrupt oscillations for the best run under normal operating conditions respectively.

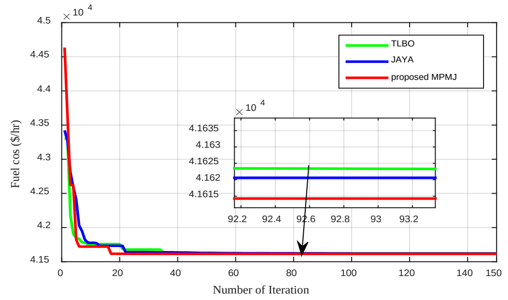

Figure 6(a). Convergence characteristic of fuel cost of generation without SSSC

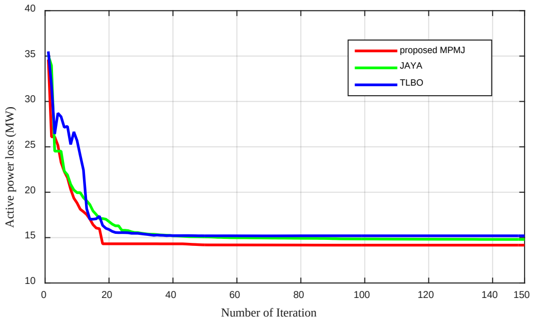

Figure 6(b). Convergence char. of active power loss without SSSC

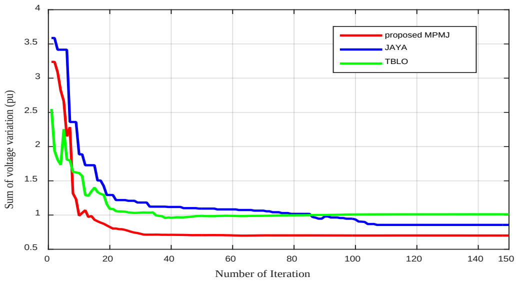

Figure 6(c). Convergence char. of voltage deviation without SSSC

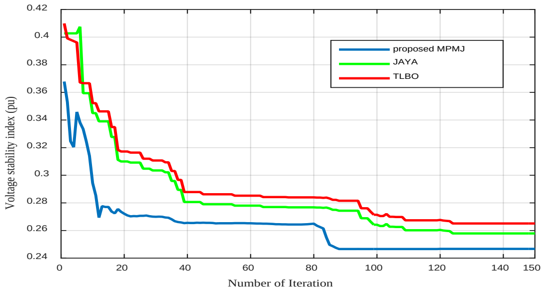

Figure 6(d). Convergence characteristic of sum of squared voltage stability index without SSSC

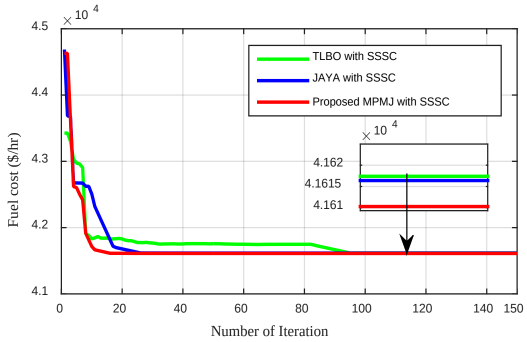

Figure 7(a). Convergence characteristic of fuel cost of generation using SSSC device

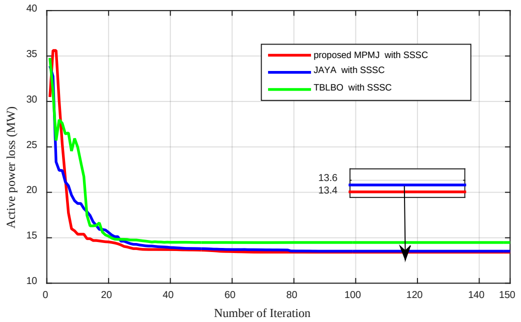

Figure 7(b). Convergence characteristic of active power loss using SSSC device

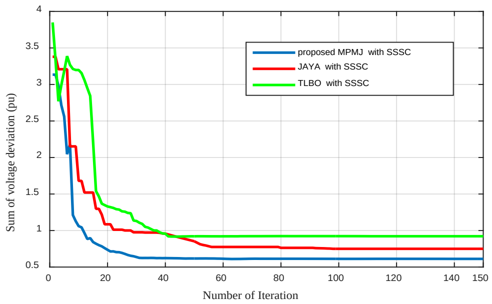

Figure 7(c). Convergence characteristic of voltage deviation using SSSC device

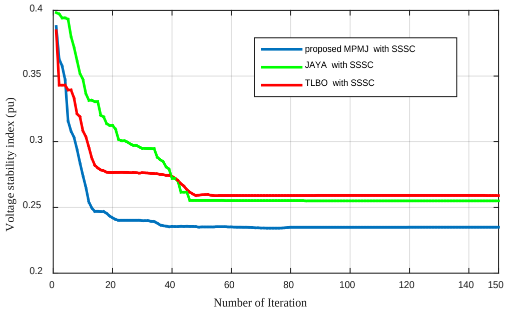

Figure 7(d). Convergence characteristic of sum of squared voltage stability index using SSSC device

Table 1. OPF results and decision table for the AHP method for IEEE-57 bus

| Alternatives | | Attributes | | | |
|---|---|---|---|---|---|
| From bus | To bus | Fuel cost ($/h) | Power loss (pu) | VSI | VD (pu) |
| 9 | 13 | 41610.3 | 0.141 | 0.235 | 0.650 |
| 9 | 12 | 41612.5 | 0.1389 | 0.237 | 0.610 |
| 54 | 55 | 41608 | 0.1341 | 0.2362 | 0.612 |
| 9 | 10 | 41608.6 | 0.1340 | 0.245 | 0.6145 |
| 56 | 41 | 41609.4 | 0.1456 | 0.241 | 0.618 |

Table 2. Pairwise comparison matrix for attributes for IEEE-57 bus

| Objective | Attributes | | | |
|---|---|---|---|---|
| | Fuel cost | Power loss | VSI | VD |
| Fuel cost | 1 | 2 | 3 | 3 |
| Power loss | 0.5 | 1 | 2 | 5 |
| VSI | 0.33 | 0.5 | 1 | 2 |
| VD | 0.33 | 0.2 | 0.5 | 1 |

Table 3. Weight matrix and value of attributes for IEEE-57 bus

| Attributes | Weightage | Subjective measurement of attributes | Assigned values |
|---|---|---|---|
| Fuel cost | 0.3905 | | |
| Power loss | 0.2761 | Eigen value | 4.1213 |
| VIS | 0.1953 | Consistency index | 0.0404 |
| VD | 0.1381 | Consistency ratio | 0.0454 |

Table 4. Weakest bus ranking by AHP methods for IEEE- 57 bus

| From bus | To bus | AHP ranking |
|---|---|---|
| 9 | 13 | 5 |
| 9 | 12 | 2 |
| 54 | 55 | 1 |
| 9 | 10 | 4 |
| 56 | 41 | 3 |

Table 5. Performance parameters comparison for IEEE 57-bus test system without and withSSSC device at line 54-55.

| Algorithm | Performance parameters | Cost | | Power loss | | Voltage Deviation | | Voltage stability index | |
|---|---|---|---|---|---|---|---|---|---|
| | | without | with | without | with | without | with | without | with |
| TLBO | Fuel cost ($/hr.) | 41622 | 41617 | 43000 | 42425 | 43248 | 42158 | 44080 | 42060 |
| | Real power loss(pu) | 0.172 | 0.167 | 0.1502 | 0.1448 | 0.19 | 0.188 | 0.20 | 0.196 |
| | ∑Voltage deviation(pu) | 1.22 | 1.12 | 2.0595 | 1.987 | 1.0111 | 0.9220 | 2.04 | 1.987 |
| | L-Index | 0.4871 | 0.423 | 0.312 | 0.3108 | 0.368 | 0.3367 | 0.2651 | 0.259 |
| | CPU time (s) | 628.3 | 627 | 696.5 | 699 | 620.6 | 624.4 | 621.5 | 622.5 |
| JAYA | Fuel cost ($/hr.) | 41619 | 411615 | 43908 | 42418 | 43228 | 42140 | 43040 | 42010 |
| | Real power loss(pu) | 0.162 | 0.157 | 0.1481 | 0.1352 | 0.189 | 0.1843 | 0.198 | 0.194 |
| | ∑Voltage deviation(pu) | 1.13 | 1.102 | 2.043 | 1.940 | 0.8561 | 0.7500 | 2.012 | 1.867 |
| | L-Index | 0.4671 | 0.408 | 0.302 | 0.294 | 0.3632 | 0.3352 | 0.2578 | 0.255 |
| | CPU time (s) | 617.3 | 618.5 | 685.5 | 688.3 | 609.6 | 613.4 | 610.5 | 611.5 |
| Proposed MPMJ | Fuel cost ($/hr.) | 41614 | 41608 | 43906 | 42348 | 43216 | 42133 | 43030.4 | 42000.6 |
| | Real power loss(pu) | 0.1601 | 0.156 | 0.148 | 0.1341 | 0.178 | 0.1744 | 0.188 | 0.1821 |
| | ∑Voltage deviation(pu) | 1.111 | 1.1010 | 2.022 | 1.913 | 0.7011 | 0.6120 | 1.986 | 1.849 |
| | L-Index | 0.4571 | 0.404 | 0.3011 | 0.294 | 0.3582 | 0.3341 | 0.2463 | 0.2362 |
| | CPU time (s) | 607.3 | 609 | 663.5 | 670.5 | 602.5 | 596 | 608.4 | 595.38 |

## 8. Conclusion

The SSSC FACTS system is one on the FACTS compensation device that connects to the transmission line in series and injects voltage to the line to regulate voltage magnitude, reactive power, and power flow in the transmission line. Meanwhile, SSSC can be operated uniformly at any value. Static synchronous series compensator increases transferable power and decreases by simply reversing the polarity of the injected voltage. The SSSC device optimal location is determined based on the optimal objective function values, such as generator fuel cost, the sum of square voltage stability index, active power loss, and total voltage deviation. The Analytical Hierarchy Process (AHP) method is used to determine the optimal location of the SSSC device in the line.

The following conclusions are drawn from the work carried out:

- The SSSC FACTS device was incorporated with the Newton Raphson load flow analysis method for optimal power flow solution. In this paper, a simple SSSC model applied for optimal power flow solution. The developed model is based on a power injection approach to preventing changes in the original Jacobian matrix.
- The optimal location of the SSSC device on the transmission line is determined using the Analytical Hierarchy Process (AHP) method.

- Incorporated the proposed Multi-Population based Modified Jaya algorithm (MPMJ) with control variables of the objective function such as the generator output power, generator voltage, the SSSC FACTS device parameter, transformer tap setting, compensator output VAr.
- The proposed MPMJ algorithm with an SSSC device set reduces the generator fuel cost, active power loss, sum of voltage variation, and squared voltage stability index under normal operating conditions.
- The proposed MPMJ algorithm compared with TLBO and JAYA algorithms, hence based on the obtained result the proposed MPMJ algorithm, is more optimal than other algorithms on the standard test system of the IEEE 57 bus system.

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