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FACTS Devices Optimization for Optimal Power Flow Using Particle Swarm Optimization In Sulselrabar System

Abstract. *This paper discusses the impact of Flexible AC Transmission System (FACTS) devices on the optimization problem of Optimal Power Flow (OPF). The Particle Swarm Optimization (PSO) technique is employed to solve the OPF problem and to obtain optimal parameter settings and allocation of FACTS devices while considering the objective function of optimizing the voltage at each bus and minimizing power losses in the transmission lines. In this study, the type of FACTS device used is the Static Var Compensator (SVC), which is applied to the Sulselrabar multimachine system. Points of analysis include the enhancement of voltage profiles at each bus and the reduction of losses in the transmission lines. The PSO optimization results yield the optimal placement and sizing of the SVC at buses 21, 30, 31, 32, 33, and 34, with respective ratings of 30, 10, 50, 20, 20, and 40 MVar. The installation of the SVC leads to an improvement in voltage profiles and a reduction in power losses in the transmission lines.*

Streszczenie. *W artykule omówiono wpływ urządzeń elastycznego systemu przesyłu prądu przemiennego (FACTS) na problem optymalizacji optymalnego przepływu mocy (OPF). Technika optymalizacji roju cząstek (PSO) jest wykorzystywana do rozwiązania problemu OPF i uzyskania optymalnych ustawień parametrów i alokacji urządzeń FACTS z uwzględnieniem funkcji celu optymalizacji napięcia na każdej szynie i minimalizacji strat mocy w liniach przesyłowych. W tym badaniu typem zastosowanego urządzenia FACTS jest Static Var Compensator (SVC), który jest stosowany w wielomaszynowym systemie Sulselrabar. Punkty analizy obejmują poprawę profili napięcia na każdej magistrali i zmniejszenie strat w liniach przesyłowych. Wyniki optymalizacji PSO dają optymalne rozmieszczenie i wielkość SVC w autobusach 21, 30, 31, 32, 33 i 34, z odpowiednimi wartościami znamionowymi 30, 10, 50, 20, 20 i 40 Mvar. Zainstalowanie SVC prowadzi do poprawy profili napięciowych oraz zmniejszenia strat mocy w liniach przesyłowych.* (***FACTS Optymalizacja urządzeń w celu uzyskania optymalnego przepływu mocy przy użyciu optymalizacji roju cząstek w systemie Sulselrabar***)

Keywords: *FACTS Devices, SVC, Sulselrabar, OPF, PSO.*
Słowa kluczowe: *FACTS Devices, SVC, Sulselrabar, OPF, PSO.*

1. Introduction

Optimal Power Flow (OPF) is one of the complicated issues that must be solved in the design and operation of contemporary power systems. It is expected that the electric power system should operate under optimal conditions to achieve maximum security and reliability. The solution to the OPF problem involves non-convex, large-scale, and nonlinear optimization challenges [1]. This aims to determine the optimal control variables of power system components, such as real power generation, generator voltage, transformer settings, reactive compensation elements, etc., in order to achieve the minimization of the objective function. Additionally, many problems related to poor power quality and high loads in the power network can be resolved by using Flexible AC Transmission System (FACTS) devices that are electronically regulated. The efficient use of existing facilities can be improved by the right placement of these devices [2, 3]. Consequently, an optimal solution that integrates the allocation of FACTS devices into the OPF problem has become an intriguing research topic to be discussed, as the implementation of FACTS devices has proven to enhance the power quality of the power system network [4, 5].

Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), and Thyristor Controlled Series Compensator (TCSC) are a few examples of the several types of FACTS controllers [6]. They have different effects on the steady-state performance of the power system because their impact depends on their capacity, type, and location [7]. Solving the OPF problem, given the challenges posed by capacity, type, and location, is an extremely difficult and complex optimization challenge. As a result, heuristic optimization techniques are employed to address this issue [8].

Until now, various approaches have been proposed in the literature to address OPF with the presence of FACTS devices, particularly utilizing metaheuristic methods like Particle Swarm Optimization (PSO) [9], Opposition Krill Herd Algorithm (OKHA) [10], Symbiotic Organisms Search (SOS) [11], Success History-based Adaptive Differential Evolution (SHADE) [2], Efficient Parallel Genetic Algorithm (EPGA) [12], Grasshopper Optimization Algorithm (GOA) dan Integrated Ant Lion Optimizer (IALO) [13], among others. Additionally, conventional techniques like Sequential Quadratic Programming proposed in [14] and the Newton method proposed in [14] have been used[15].

Several comparison investigations have been explored and carried out in related publications about the effectiveness of metaheuristic algorithms in solving engineering challenges, as demonstrated in [16]. According to the literature study, using metaheuristic algorithms to solve engineering challenges is becoming more and more commonplace, especially when it comes to the OPF problem. The use of these metaheuristic algorithms produces the best possible computational outcomes, particularly when dealing with power system problems.

In this study, an approach is proposed using a PSO-based metaheuristic method to address the placement and rating problem of SVC. PSO is a method that adopts the behavior of particles in a group as they search for food sources [17]. PSO is capable of performing computations effectively, especially for complex problems [18]. The case study employed in this research focuses on the Sulawesi South, Southeast, and West (Sulselrabar) power system. The PSO optimization method is utilized to tackle the OPF problem while taking into account the presence of FACTS devices within the power system network. The contributions of this paper can be outlined as follows:

- Implementation of the PSO algorithm for solving the OPF in the Sulawesi South, Southeast, and West (Sulselrabar) power system.
- Solving OPF using SVC deployment to address undervoltage and overvoltage issues, as well as power losses.

This paper is composed of several sections, including: Section 2 discusses the OPF formulation, Section 3 provides a brief description of the methods used, Section 4 covers the implementation of the PSO algorithm in solving the OPF, and Section 5 presents the conclusions drawn from this paper.

2. Modeling

2.1. SVC Modeling

An SVC is a shunt compensator capable of injecting or absorbing reactive power. SVCs are parallel-connected devices that can modify the flow of reactive power at their connection point [19]. Primarily, an SVC acts as a variable inductor or capacitor. Thyristor-switched reactor and thyristor-controlled capacitor are shunt-connected to the power system. The static SVC model is depicted in Figure 1.

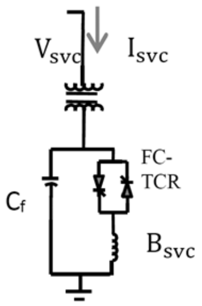

Fig.1. SVC static models

Following is a relationship between the VAr injected or absorbed at a bus by an SVC:

(1) $Q_{svc} = V^2 B_{svc}$

Where B_{svc} and *'V'* are the susceptance and bus voltage, respectively.

2.2. Optimal SVC Placement

The optimal location of the SVC is determined by analyzing the PV curve. The PV curve is constructed using advanced power flow techniques (OPF). Conventional power flow methods fail at the point of bifurcation or maximum load capability due to singularities in the Jacobian matrix. Therefore, OPF was developed to search for power flow at all load points by slightly modifying the power flow equations. OPF uses predictor and corrector schemes to find power flow solutions at all load points as shown in Figure 2.

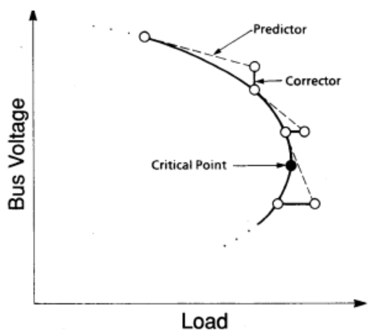

Fig.2. The predictor and corrector scheme used in OPF [20]

Further details about OPF are provided in [20]. Due to the absence of issues with Jacobian matrix singularity in the OPF technique, power-voltage (PV) curves can be obtained for any system at any load point. PV curves for all load buses are constructed, and buses exhibiting higher voltage deviations in response to load changes are considered weak buses, thus being potential locations for SVC placement. OPF is a well-constructed technique and is available in many commercial software packages.

3. Proposed Algorithm

3.1. Particle Swarm Optimization (PSO)

PSO stands for population-based optimization. A problem space is first covered by a group of particle populations in PSO. Swarm [21] is the term used to describe these scattered particles. The existence of this particle and the potential value it could produce are both recorded in this particle. In order to determine which particles are in the position that will produce the best results for a movement, particles will exchange information with one another. Based on a motion function known as velocity, other particles will then move to that position in response to this information. Each particle chooses its own position during flight based on its own experience *(P_{best})* and other particles' experiences *(G_{best})*. In Fig. 3, the procedure for locating P_{best} and G_{best} is depicted.

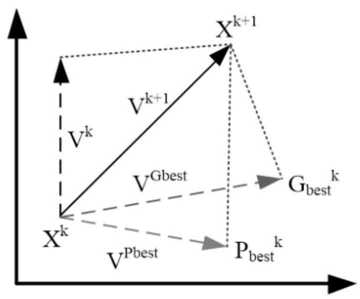

Fig.3. The PSO concept [21]

(2) Each particle's speed can be calculated from (2).

$$v_{k+1} = w.v_k + c_1 rand \times (P_{best} - x^k) + c_2 rand \times (G_{best} - x^k)$$

P_{best} and G_{best} can be computed based on particle velocity using (2). You can find your current position by going to (3) [22].

(3) $$x^{k+1} = x^k + v_{k+1} . k = 1,2 \dots n$$

where: X^k = present search area; X^{k+1} = search position changed; V^k = existing speed; V^{k+1}= changed speed; Vp_{best}= P_{Best} Speed; Vg_{best} = G_{best} Speed; n = Size of a collection of particles; m= The particle's membership count; p_{best-i}= P_{best} from k; g_{best-I} = G_{best} from group; w = Weight; c_i = The weighting factor for the subsequent terms; - c_1 and c_2 are positive constants; - r_1 and r_2 are random numbers

The following is the iteration function of k and w is the weight of inertia (4).

(4) $$w(k) = w_{max} - \left(\frac{w_{max} - w_{min}}{max.iter}\right) \times k$$

The maximum speed is as follows to guarantee that all dimensions move at the same rate (5).

(5) $$v^{max} = \frac{(x^{max} - x^{min})}{N}$$

N stands for the maximum allowed number of iterations. The PSO parameters utilized in this study are displayed in Table 1.

Table 1. PSO Parameters [23]

Particles	30
Iteration	50
Number of Variables	3
C_2 (Social Constant)	2
C_1 (Cognitive Constant)	2
W (Inersia Moment)	0.9

3.2. Objective Function

The primary objective of solving the OPF problem is to optimize the steady-state performance of the power system in terms of a single objective function by choosing suitable operating points and taking into account a number of technical and economic constraints imposed by the installed devices and the electric power network. This can be conceptualized mathematically as a nonlinear optimization problem, such as:

Minimize f(x)
Subject to: g(x) = 0
h(x) ≤ 0

Where *x* is a vector of control and state variables, *f(x)* is the objective function, *h(x)* and *g(x)* are sets of inequality and equality constraints, respectively. The state variables include the voltage and angle of load buses, whereas the control variables include the active and reactive power outputs of generators, bus voltages, and transformer tap settings [24].

The active power loss in the transmission network is the minimized objective function and is illustrated as follows [25]:

$$\sum_{k}^{N} = \mathbf{1} g_k \left[V_i^2 + V_j^2 - 2 V_i V_j \cos\theta_{ij} \right]$$

g_k is the conductance of the branch between bus *I* and bus *j*, V_i and V_j are the voltages at these buses, and B_{ij} stands for the phase angle difference. *N* is the number of transmission lines.

The optimization process of PSO is illustrated in Figure 4 with the convergence plot. From the graph, it is observed that the PSO method undergoes optimization for 50 iterations, and it finds the optimal point in the 21st iteration with a minimum fitness function value of 9.388e+07.

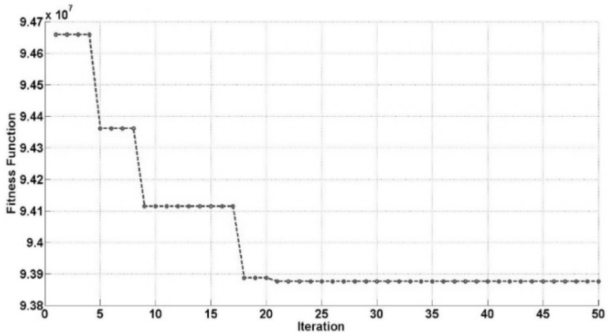

Fig. 4. PSO Convergence Graph

4. Results and Discussion

The power flow of the Sulselrabar system before the Static Var Compensator was included is examined as the analysis's first step (SVC). Before the SVC was installed, Table 2 gives a preliminary profile of the Sulselrabar system conditions. From the power flow calculation results, several bus voltage profiles are identified to be in marginal and critical conditions. According to the system operation standards, the minimum bus voltage is allowed to vary within a range of ±5%. Based on the provided table, the buses that experience marginal and critical conditions are as follows:

Marginal conditions: Bus 6, 7, 8, 20, 25, 26, and 29.

Critical conditions: Bus 21, 22, 23, 24, 30, 31, 32, and 33.

Tabel 2. Voltage Profile

	Voltage before Optimization				Voltage after Optimization			
Bus No	Voltage Mag	Angle Degree	Injected Mvar	SVC MVar	Voltage Mag	Angle Degree	Injected Mvar	SVC MVar
1	1.1	0	0	0	1.1	0	0	0
2	1.05	-2.47784	0	0	1.05	-2.428433	0	0
3	1.03	-3.26805	0	0	1.05	-3.4822	0	0
4	1.04	-2.41161	0	0	1.05	-2.5019	0	0
5	0.99	-6.92195	0	0	1.05	-7.4691	0	0
6	0.95	-18.0957	0	0	1.05	-17.4148	0	0
7	0.95	-18.5398	0	0	1.05	-17.78604	0	0
8	0.95	-17.5208	0	0	1.05	-16.94406	0	0
9	0.99	-14.0356	0	0	1.03	-13.3915	0	0
10	1	-11.0487	0	0	1.02	-10.4159	0	0
11	1	-9.72978	0	0	1.02	-9.2125	0	0
12	1	-0.58802	0	0	1.03	-0.9377	0	0
13	1.01	4.458059	0	0	1.04	3.7624	0	0
14	1	-9.19201	0	0	1.01	-9.10032	0	0
15	1	-11.2008	0	0	1	-10.9296	0	0
16	0.97	-19.2086	0	0	1.04	-18.0552	0	0
17	1.064063	-2.12857	0	0	1.072451	-2.2194	0	0
18	1.047687	-3.99122	0	0	1.056259	-4.053021	0	0
19	1.039252	-5.00138	0	0	1.047908	-5.0468	0	0
20	0.954285	-13.7252	0	0	1.057884	1.05788	0	0
21	0.948297	-15.7062	0	0	1.057845	-15.5957	0	30
22	0.936765	-18.5199	0	0	1.038088	-17.7636	0	0
23	0.916144	-20.8519	10	0	1.01977	-19.6546	10	0
24	0.94247	-18.3364	0	0	1.043224	-17.6093	0	0
25	0.957258	-16.8693	0	0	1.038261	-16.2998	0	0
26	0.966458	-15.8708	0	0	1.033937	-15.3683	0	0
27	0.990014	-6.94329	0	0	1.014907	-6.7051	0	0
28	1.004552	-2.62505	0	0	1.033764	-2.9713	0	0
29	0.953917	-15.0352	0	0	1.04157	-14.7226	0	0
30	0.933897	-13.5349	0	0	1.0397	-14.9891	0	10
31	0.912991	-14.8248	10	0	1.049811	-16.8596	10	50
32	0.931039	-18.892	0	0	1.046512	-19.0746	0	20
33	0.934117	-18.8711	0	0	1.046124	-18.9442	0	20
34	0.94244	-18.2827	0	0	1.042953	-18.1359	0	40
35	0.946219	-18.1889	0	0	1.046456	-17.7738	0	0
36	0.946222	-18.189	0	0	1.046459	-17.7743	0	0
37	0.923591	-19.9664	0	0	1.026284	-18.9382	0	0

After conducting an analysis of the optimal placement and tuning of the SVC using PSO optimization, the optimal placement and tuning locations are determined for 6 buses. Specifically, bus 21 is adjusted by 30 MVar, bus 30 by 10 MVar, bus 31 by 50 MVar, buses 32 and 33 by 20 MVar each, and bus 34 by 40 MVar. Figure 5 illustrates the bus voltage profile of the Sulselrabar system before and after the installation of the SVC. As a result of the SVC installation, the voltage profile of the buses has improved, transitioning from marginal and critical conditions to normal operating conditions.

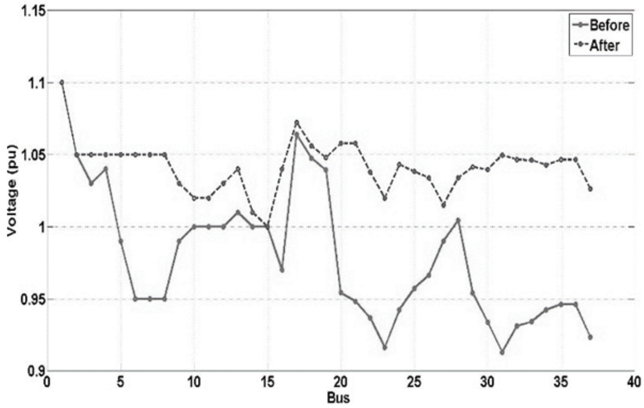

Fig.5. Bus Voltage Profile before and after adding SVC

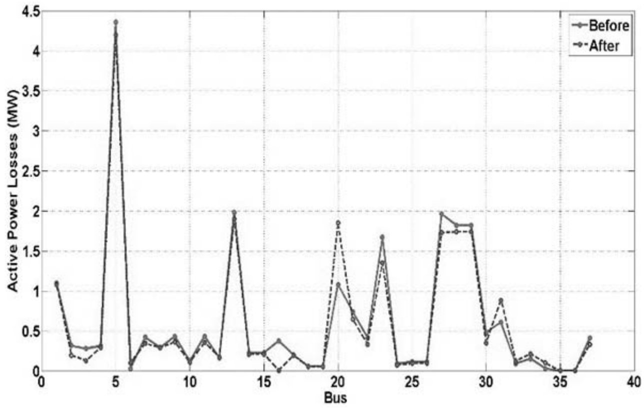

Fig.6. Active Power Losses Profile

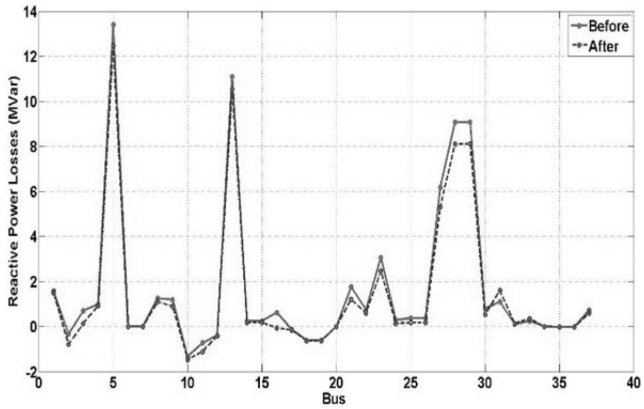

Fig.7. Reactive Power Losses Profile

The reactive power injection obtained from the SVC also contributes to the improvement of power flow in the transmission system, making it more optimal. This enhanced power flow improvement in the system results in a reduction of power losses. The optimized power flow improvements in the system lead to a decrease in power losses, which ultimately contributes to the overall efficiency and reliability of the power transmission network. Figures 6 and 7 depict the comparison of active and reactive power loss profiles before and after the installation of the SVC. The active power losses before SVC installation amounted to 22.9335195 MW, and after the SVC installation, they decreased to 21.86307805 MW. Meanwhile, the reactive power losses before SVC installation were 61.24536683 MVAR, and after the SVC installation, they decreased to 52.31576837 MVAR. These reductions in power losses signify the positive impact of the SVC on enhancing the overall efficiency and performance of the power system.

5. Conclusion

The placement of the SVC optimizes the reactive power distribution in the system, addressing changes caused by undervoltage and overvoltage conditions, thereby fulfilling the load requirements. The active power losses before SVC installation were 22.9335195 MW, and after the SVC installation, they decreased to 21.86307805 MW. Likewise, the reactive power losses before SVC installation were 61.24536683 MVar, and after the SVC installation, they decreased to 52.31576837 MVar. These results illustrate the positive impact of the SVC optimization on both voltage stability and power loss reduction in the system.

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