RESEARCH PAPER

Deployment of PSO controlled SVC & SAF for the power quality enhancement in standard electrical systems

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ABSTRACT

Power quality problems may arise from the connecting of several generating units to accommodate high load demands. The voltage profiles during load changes may be disrupted by the violation of reactive power under the limitations. A Shunt Active Filter (SAF) and Static Var Compensator (SVC) are strategically placed throughout the network to improve power quality and correct for reactive power in order to lessen these problems. The lines with the biggest power losses, lowest voltage profiles, maximum Total Harmonic Distortion (THD), and poorest Power Factor (PF) under various load circumstances are identified to establish the best location for SVC and SAF. Enhancing voltage profiles, reducing real power losses, and improving overall power quality are the goals of SVC and SAF adoption. This is accomplished by creating a multi-objective function that takes into account variables including power loss, voltage stability, THD, and PF. Within a closed-loop architecture, a PID controller controls the switching operations of converters in the SVC and SAF. Particle Swarm Optimization (PSO) is used to examine performance indicators such as voltage, THD, and power factor. Improved voltage profiles, less THD, and increased power factor are all demonstrated by the use of PSO with PID based SVC regulating. Simulations on IEEE 39 bus systems are used to verify the effectiveness of the suggested approach.

Index Terms: THD, voltage, power factor, PSO

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INTRODUCTION

The review of the literature starts with [1], which describes the usage of a hybrid shunt compensator in an interconnected EHV transmission line to optimize the voltage profile and correct power factor using a mixed SVC and a static synchronous compensator (STATCOM). The article [2] suggests a new collaborative control approach that makes use of expert choices for the integrated system, which consists of an AC grid with a low THD thyristor-zed SVC connected to a DC microgrid via a D-STATCOM, which also serves as a bidirectional power converter.

To improve the electrical performance of the electrical arc furnace in the distribution energy system, a reactive power adjustment technique is suggested in [3]. Both a static variable compensator (SVC) and active filtering may simultaneously equalize three phase currents and modify the power factor. The instantaneous state of an SVC can be fixed by the active filter. The power output of the active filter may then be reduced by an SVC. Finally, field measurement data from a metal foundry was used for an analysis.

The construction, coordinate control process, and parameter design of an amalgam system for active power injection and nonactive power (reactive, harmonic, and imbalanced power) correction are presented in [4]. The proposed hybrid architecture consists of a grid-connected inverter with capacitive coupling and a SVC.

The study [5] presents a two-step approach to the optimal regulation of voltage issues in an unbalanced radial distribution network with photovoltaic production. The static VAr compensator and the on-load tap changer are the voltage control systems that have been examined in this study. It takes more than eight hours to solve the voltage management problem, which is a mixed-integer nonlinear programming problem. In [6], a study on sensitivity analysis of voltage variation for unbalanced distribution networks resulting from variations in photovoltaic output was carried out.

The paper [7] presents a distributed static synchronous compensator (D-STATCOM) control strategy to minimize voltage variance in both positive and negative

sequences. The D-STATCOM simultaneously serves as the basic positive-sequence admittance and basic negative-sequence conductance in order to restore the positive-sequence voltage to its initial value and reduce the negative-sequence voltage to a level that is acceptable. The three-layer coordinated management of the hybrid functioning of the static synchronous compensator and SVC was assessed in a study published in [8].

The paper [9] presents TCL compensation for dynamically reactive power offset in a smart grid system. Compared to traditional static variable compensators, like a FC-TCR, which generates low-order harmonic currents, the proposed TCLC can significantly reduce the application of harmonics. This work investigates the choice of TCLC parameters while considering the reactive energy compensation band and the denial of currents with harmonics. A hybrid system including a hybrid static variable compensator and a hybrid active power filter (SVC/HAPF) has been investigated for medium-voltage heavy load correction in [10].

design and load flow analysis of ieee 39 bus system

The IEEE 39 bus system consisting of 10 generators, 46 transmission lines, and 19 loads. The load flow analysis of the IEEE 39 bus system was done using the Gauss seidel method. The relevant parameters, such as voltage profile and real power loss, obtained from load flow analysis under 10% loading variation of the IEEE 39 bus system are shown in Table 1. According to Table 1, Bus Nos. 1, 9, and 39 have the worst voltage profiles. These busses also have the worst power factor, high THD(%), and very high actual power loss as compared to another bus. In terms of real power losses, voltage profile, total harmonic distortion (THD), and power factor (PF), Bus No. 1 and Bus No. 9 have the weakest performance metrics among these three busses. Bus No. 1 has an active filter attached, and Bus No. 9 has an SVC linked in compliance with the directive to adhere to the working principle.

Table.1 Performance parameters of IEEE 39 bus system under 10% loading conditions

Bus no.	Voltage (p.u)	Power factor(PF)	THD(%)	line	line	real power loss(p.u)
1	**0.8775**	**0.79**	**9.4**	1	2	0.00343
2	1.0013	0.91	8.9	1	39	0.00098
3	0.98	0.91	9.1	2	3	0.001274
4	0.95	0.87	7.1	2	25	0.00686
5	0.94	0.84	7.3	3	4	0.001274
6	0.934	0.84	7.4	3	18	0.001078
7	0.914	0.86	7.2	4	5	0.000784
8	0.9	0.89	7.3	4	14	0.000784
9	**0.86**	**0.82**	**8.8**	5	6	0.000196
10	0.97	0.91	7.1	5	8	0.000784
11	0.96	0.94	7.2	6	7	0.000588
12	0.95	0.95	7.4	6	11	0.000686
13	0.96	0.89	7.3	7	8	0.000392
14	0.97	0.9	7.2	8	9	0.002254
15	0.98	0.91	7.1	9	39	0.00098
16	1.01	0.92	7.4	10	11	0.000392
17	1	0.93	7.6	10	13	0.000392
18	0.99	0.94	7.5	13	14	0.000882
19	1.04	0.89	7.4	14	15	0.001764
20	0.98	0.91	7.3	15	16	0.000882
21	1.01	0.92	7.2	16	17	0.000686
22	1.04	0.93	7.1	16	19	0.001568
23	1.03	0.88	7.3	16	21	0.000784
24	1.01	0.85	6.9	16	24	0.000294
25	1.03	0.86	7.1	17	18	0.000686
26	1.03	0.87	6.8	17	27	0.001274
27	1.01	0.9	6.5	21	22	0.000784
28	1.04	0.91	6.7	22	23	0.000588
29	1.04	0.9	7.2	23	24	0.002156
30	1.04	0.91	7	25	26	0.003136

31	0.98	0.89	6.9	26	27	0.001372
32	0.98	0.91	7.3	26	28	0.004214
33	0.99	0.9	7.1	26	29	0.005586
34	1.01	0.91	7.4	28	29	0.001372
35	1.04	0.93	7.5	12	11	0.001568
36	1.06	0.94	7.4	12	13	0.001568
37	1.02	0.92	7.3	6	31	0
38	1.02	0.93	7.2	10	32	0
				19	33	0.000686
				20	34	0.000882
				22	35	0
				23	36	0.00049
				25	37	0.000588
				2	30	0
				29	38	0.000784
39	**0.89**	**0.81**	**8.9**	19	20	0.000686

description of SVC and active shunt filter

This section will briefly describe the SVC and active shunt filter, which are placed at the respective positions of IEEE 39 bus systems for the enhancement of power quality parameters and voltage profile. Let's discuss these parameters one by one.

3.1 Static Var Compensator (SVC):

By supplying or absorbing the reactive power, SVC is primarily used to maintain a steady voltage and improve the other power quality metrics. The benefits of utilizing SVC are as follows:

- Reduces line losses and improves power transmission efficiency
- Increasing the load's power factor

Enhancing the momentary stability

- Managing the temperature in a steady state

• Because there are no moving parts, less maintenance is needed.The structure of SVC is shown in Fig.1, in which the filter, TSC(Thyristor switch capacitor), and TCR(Thyristor controlled reactor) are connected to a common bus, which is further connected to the transmission line via a transformer. The switching of converters has been controlled with a PID controller.

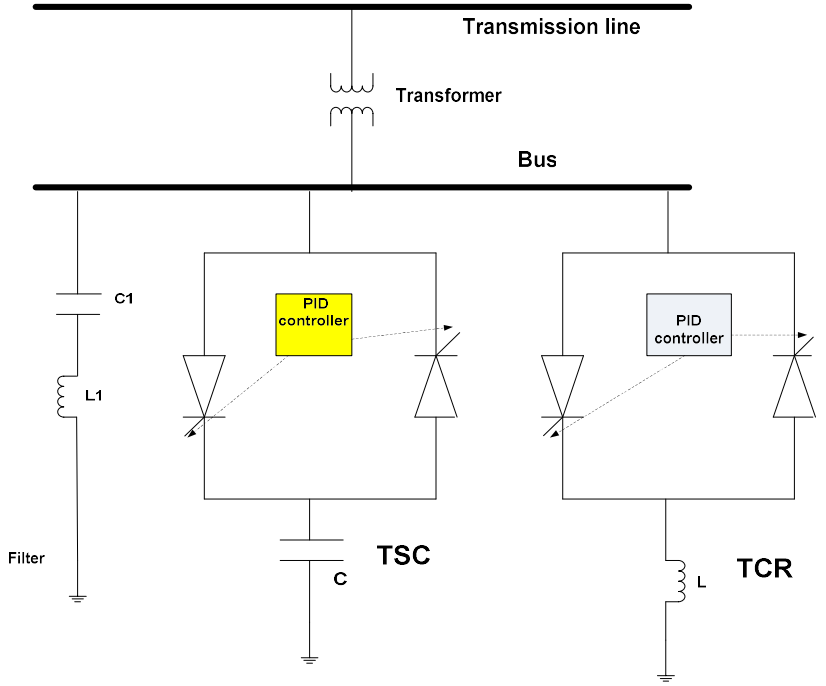


Fig.1 Structure of SVC

3.2 Active filter:

The structure of the active filter has been illustrated in Fig.4, in which a single-phase inverter is connected between the AC source and non-linear loads. The control of a single-phase inverter is done with a PID controller.

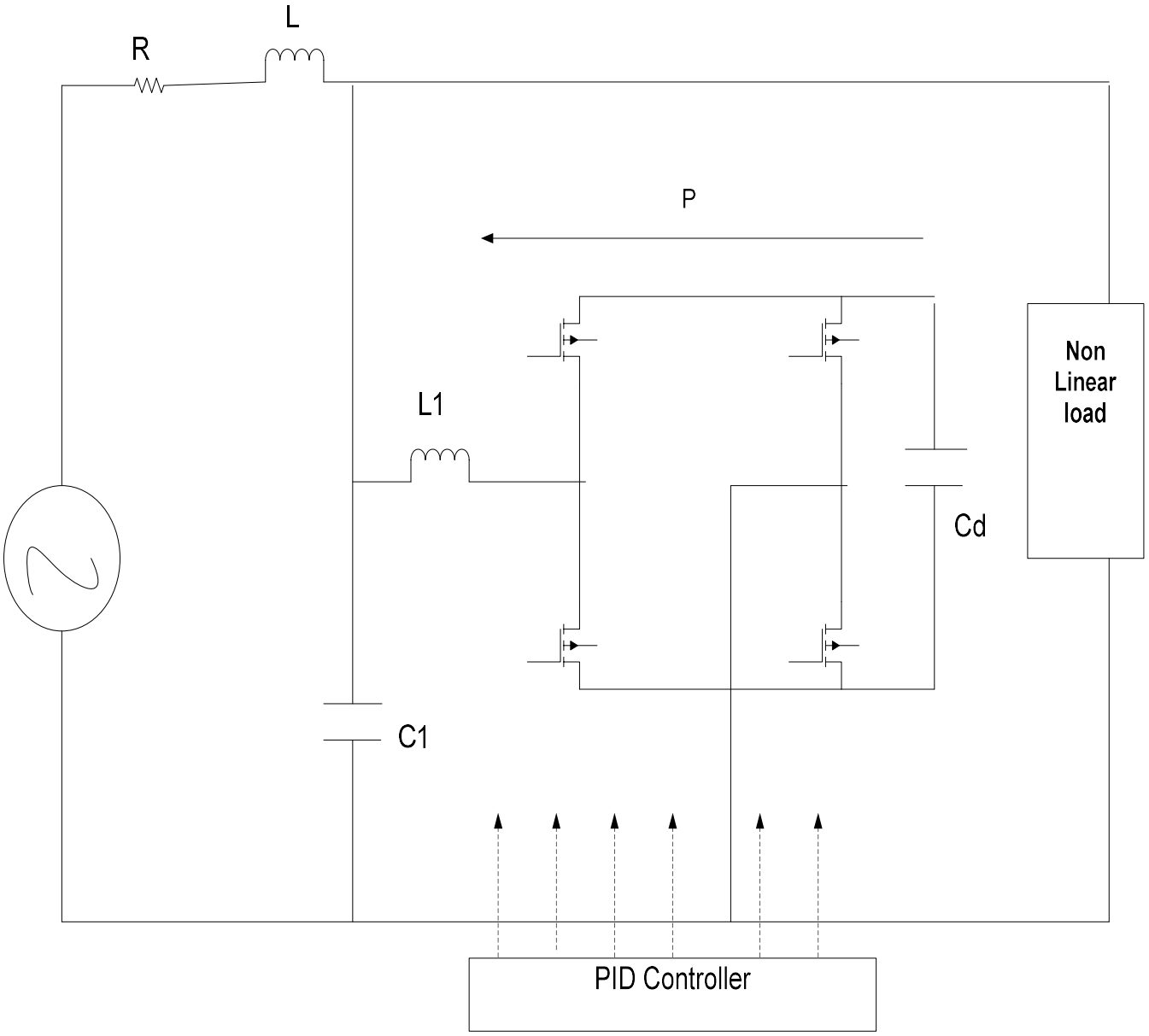


Fig.2 Structure of Active filter

IMPLEMENTATION OF PSO

The PSO approach involves a population of individuals [11]. For the sentence to make sense, these individuals are likened to a swarm of soaring birds. Over many generations, these species cooperate and compete to find the best solution to a given problem or the status of the world's fittest. Every bird adjusts its flight path according to its own flying experiences as well as those of its buddies. Every bird has a "particle" abstracted into a single place in a D-dimensional universe. The generic expressions for the velocity particle and location particle in the next iteration are shown in equations 1 and 2.

$$v(t+1) = \omega(t)v(t) + c_1 r_1 (pbest(t) - x(t)) + c_2 r_2 (gbest(t) - x(t)) \quad (1)$$

$$x(t+1)=x(t)+v(t+1) \quad (2)$$

where t is the present value of the iteration. With t, the inertial weight parameters, or ω, changes. The distribution of two random number uniforms, namely r1 and r2, is between 0 and 1. C1 and C2 are the two corresponding accelerometer constants.

Fig. 3 shows a flowchart that illustrates the process of describing the PSO

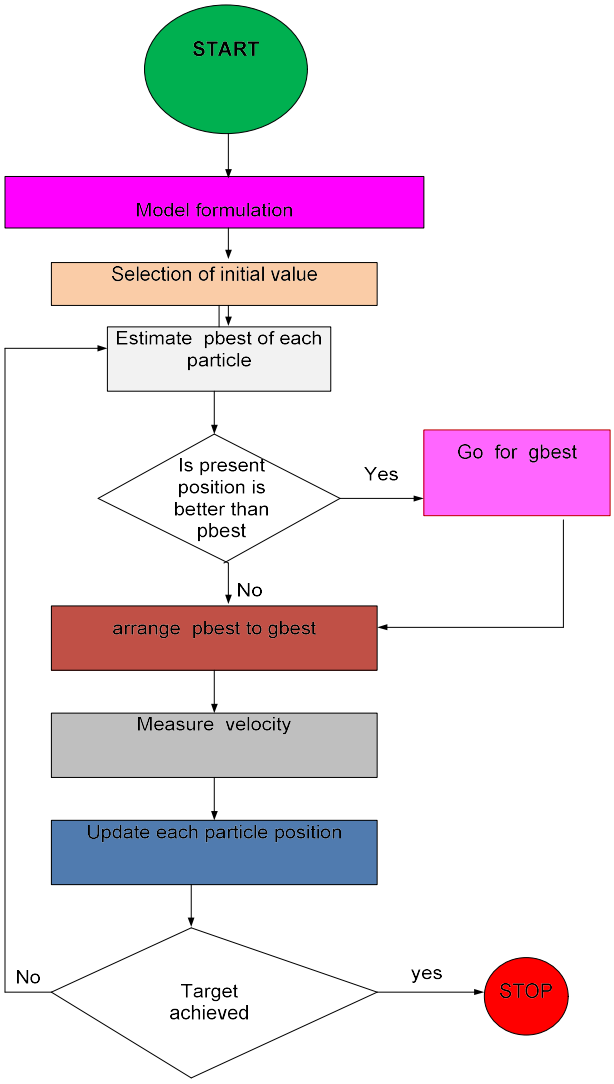


Fig.3 Flowchart illustrating the PSO

IV. IMPLEMENTATION AND CONTROLLING OF SVC AND ACTIVE SHUNT FILTER USING PID CONTROLLER

The controlling of svc and active shunt filter will be discussed one by one

4.1 Switching and controlling of SVC using PID controller

A PID controller was used to measure the three-phase voltage from the bus in order to evaluate the control of SVC. The Clarke and Park transformation is used to change this three-phase voltage (abc) to dq0 voltage. The converted voltages, Vd and Vq, are compared to their reference values (Vd* and Vq*) and then go via PID controllers (PID1 and PID2), which produce errors e1 and e2 as indicated in Equations 3 and 4.

$$(V_d - V_d^*)(k_{p1} + sk_{d1} + \frac{k_{i1}}{s}) = e_1 \quad (3)$$

$$(V_q - V_q^*)(k_{p2} + sk_{d2} + \frac{k_{i2}}{s}) = e_2 \quad (4)$$

The difference between errors gives reference voltage as shown in Eq.5

$$V_{ref} = e_1 - e_2 \quad (5)$$

The structure of SVC controlling with PID controller is shown in Fig.4.

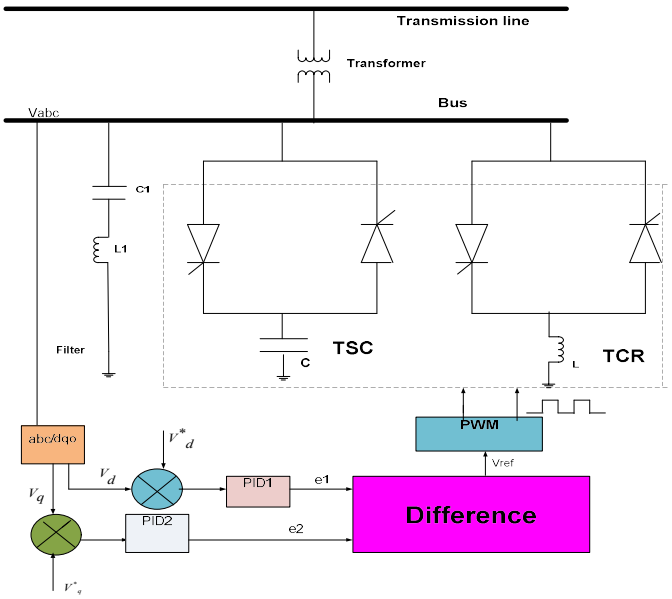


Fig.4 Controlling of SVC using PID controller

4.2 Switching and controlling of Active shunt filter using PID controller

The active shunt filter's control has been assessed using a PID controller. The technique begins with measuring the three-phase voltage from the bus. The Clarke and Park transformation is then used to convert the three-phase voltage (abc) to the dq0 voltage. The converted voltages, Vd and Vq, are compared to their reference values, Vdc and Vq*, and then they go via a PID controller (PID3 and PID4), which yields errors e3 and e4 as indicated in Equations 6 and 7. In the end, the DC link voltage (Vdc = Vd *) is the reference value of Vd *.

$$(V_d - V_{dc})(k_{p3} + sk_{d3} + \frac{k_{i3}}{s}) = e_3 \quad (6)$$

$$(V_q - V_q^*)(k_{p4} + sk_{d4} + \frac{k_{i4}}{s}) = e_4 \quad (7)$$

The structure of active filter controlling using PID controller is shown in Fig.5. The output will be intersection of two inputs e_3 and e_4 which is shown in Eq.8

$$V_{ref} = e_3 - e_4 \quad (8)$$

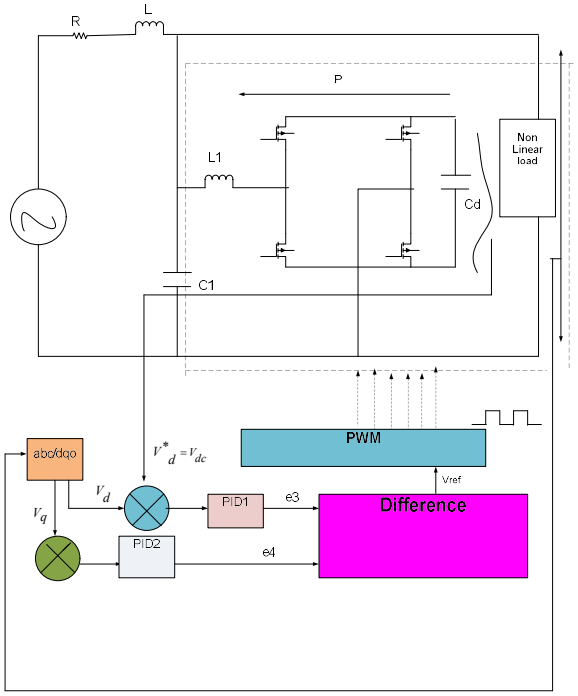


Fig.5 controlling of active filter using PID controller

V. PERFORMANCE ANALYSIS OF SVC AND ACTIVE SHUNT FILTER BASED IEEE 39 BUS SYSTEM

The performance analysis for monitoring voltage profile and power quality metrics like THD (%), power factor (pf), and real power loss (p.u.) has been assessed using IEEE 39 tested systems. The PSO has been used to assess several performance metrics, including as voltage, THD (%), power losses, and power factor, in order to enable PID-controlled SVC devices.As indicated in Table 1, it was discovered that Bus Nos. 1 and 9 had poor performance metrics. Consequently, bus No. 9 has an SVC, and bus No. 1 has an active filter.

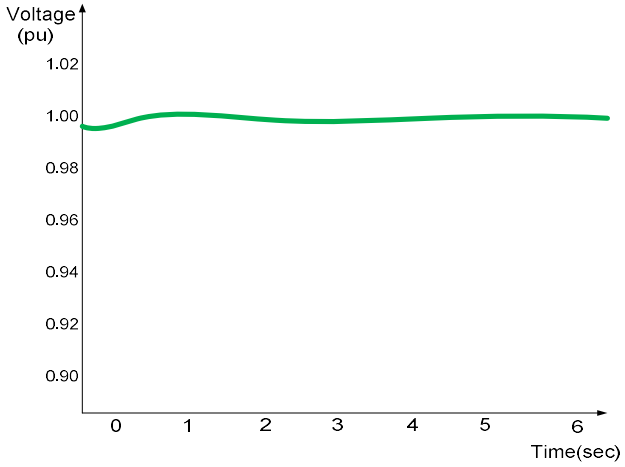


Fig.6 Voltage at bus no. 1 of IEEE 39 bus system with PSO

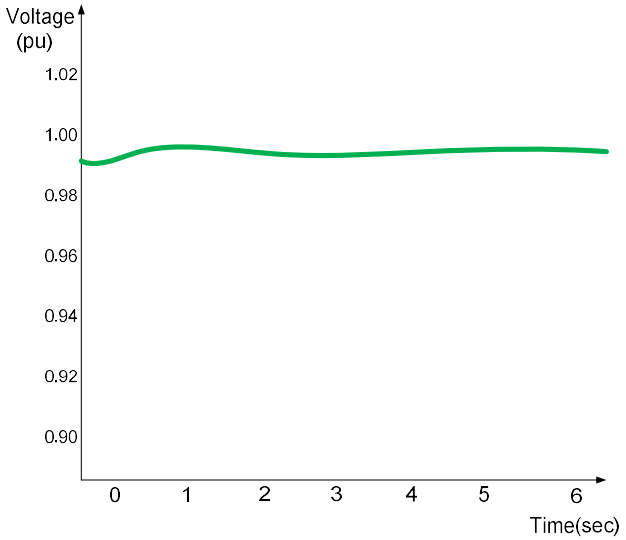


Fig.7 Voltage at bus no.9 of IEEE 39 bus system with PSO

Table.2 Voltage profile(p.u) at different buses of IEEE 39 system using PSO and without -PID based SVC

Bus No.	**PSO[11] with PID based SVC**	**Without PID based SVC**
1	0.99	0.79
2	0.94	0.82
3	0.94	0.9
4	0.95	0.87
5	0.96	0.86
6	0.95	0.85

7	0.94	0.83
8	0.92	0.82
9	0.99	0.78
10	0.99	0.89
11	0.98	0.88
12	0.97	0.87
13	0.98	0.88
14	0.99	0.89
15	1	0.9
16	0.95	0.93
17	0.94	0.92
18	1.01	0.91
19	0.98	0.96
20	1	0.9
21	0.95	0.93
22	0.98	0.96
23	0.97	0.95
24	0.95	0.93
25	0.97	0.95
26	0.97	0.95
27	0.95	0.93
28	0.98	0.96
29	0.99	0.96
30	0.98	0.96
31	0.94	0.9
32	0.95	0.9
33	0.96	0.91
34	0.95	0.93
35	0.98	0.96
36	1	0.98
37	0.96	0.94
38	0.97	0.94
39	0.91	0.81

Table.3 Power factor at different buses of IEEE 39 system using PSO with and without PID based SVC

Bus No.	**PSO[11] with PID based SVC**	**Without PID based SVC**
1	0.77	0.71
2	0.89	0.83
3	0.89	0.83
4	0.85	0.79
5	0.82	0.76
6	0.82	0.76
7	0.84	0.78
8	0.87	0.81
9	0.8	0.74

10	0.89	0.83
11	0.88	0.86
12	0.9	0.87
13	0.87	0.81
14	0.88	0.82
15	0.89	0.83
16	0.9	0.84
17	0.89	0.85
18	0.9	0.86
19	0.87	0.81
20	0.89	0.83
21	0.9	0.84
22	0.89	0.85
23	0.86	0.8
24	0.83	0.77
25	0.84	0.78
26	0.85	0.79
27	0.88	0.82
28	0.89	0.83
29	0.88	0.82
30	0.89	0.83
31	0.87	0.81
32	0.89	0.83
33	0.88	0.82
34	0.89	0.83
35	0.88	0.85
36	0.89	0.86
37	0.9	0.84
38	0.89	0.85
39	0.79	0.73

Table.4 THD(%) at different buses of IEEE 39 system using PSO with and without PID based SVC

Bus No.	**PSO[11] with PID based SVC**	**Without PID based SVC**
1	7	10
2	6.9	9.5
3	7.1	9.7
4	5.1	7.7
5	5.3	7.9
6	5.4	8
7	5.2	7.8
8	5.3	7.9
9	6.3	9.4

10	5.1	7.7
11	5.2	7.8
12	5.4	8
13	5.3	7.9
14	5.2	7.8
15	5.1	7.7
16	5.4	8
17	5.6	8.2
18	5.5	8.1
19	5.4	8
20	5.3	7.9
21	5.2	7.8
22	5.1	7.7
23	5.3	7.9
24	4.9	7.5
25	5.1	7.7
26	4.8	7.4
27	4.5	7.1
28	4.7	7.3
29	5.2	7.8
30	5	7.6
31	4.9	7.5
32	5.3	7.9
33	5.1	7.7
34	5.4	8
35	5.5	8.1
36	5.4	8
37	5.3	7.9
38	5.2	7.8
39	6.9	9.5

Tables 2 to Table. 4 of the IEEE 39 bus system display the voltage profile, power factor, and THD (%) as measured by the PSO [11] with the assistance of a PID-based SVC controller and without SVC. Figures 6 and 7 display the voltage profile at bus numbers 1 and 9 of the IEEE 39 bus system with PSO. PSO implementation has been found to improve the IEEE 39 bus system's voltage profile (pu), THD (%), and power factor.

vi . conclusion

Connecting multiple generating units to meet high load demands may result in issues with power quality. The violation of reactive power under the restrictions may cause disruptions to the voltage profiles during load changes. To reduce these issues, a SAF and SVC are positioned strategically throughout the network to enhance power quality and adjust for reactive power. The optimal site for SVC and SAF is determined by identifying the lines with the largest power losses, lowest voltage profiles, most Total Harmonic Distortion (THD), and poorest Power Factor (PF) under different load conditions.

Adoption of SVC and SAF aims to improve voltage profiles, lower real power losses, and improve overall power quality. The SVC and SAF converters' switching functions are managed by a PID controller in a closed-loop architecture. Performance metrics including voltage, THD, and power factor are examined using PSO. The integration of PSO with PID-based SVC regulation shows improved voltage

profiles, reduced THD, and enhanced power factor. The efficacy of the proposed method is confirmed by simulations on IEEE 39 bus systems.

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