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SECURITY ENHANCEMENT AND LOSS REDUCTION IN DEREGULATED POWER SYSTEMS WITH A SERIES FACTS DEVICE

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ABSTRACT

Safety and congestion management of electricity systems is an essential concern in competitive markets. The operation of a transmission system within the operating limits is also the main task performed by system operators. In this research, a novel strategy for preserving the integrity of the system while decentralizing power market activities is described. The interior point method, integrated with evolutionary particle swarm optimization, also known as IPM-EPSO, is utilized in order to solve the optimal power flow problem, which aims to maximize the social benefit and system safety in the event of a contingency that is selected to be the most severe possible for the network. The effectiveness of the approach proposed was demonstrated by modified 14-bus IEEE systems for a specific loading condition, subject to contingency. The results show that under the selected network contingency conditions, the proposed technique IPM-EPSO can effectively improve system security.

Keywords: *Power System Security, Contingency Analysis, Static Security Assessment, Composite Logic Criteria, IPM-EPSO.*

1. INTRODUCTION

In view of the past and present difficulties in order to create additional power lines and to expand substantially the power purchases relevant to competitive electricity markets, electricity utilities must be operated closer to their limits. Therefore, the maintenance of system safety is one of the major concerns of market and system operators more than ever before [1, 2]. Here, Flexible AC transmission systems (FACTS) are introduced by efficient power flow and improved transmission line stability, changed the face of power system operation. FACTS controls can reduce the active power loss in the system, resulting in an efficient utilization of existing power systems in addition to improving the security of the system [3 – 6].

By using customized security constrained optimum power flow programs [7] the settings and operating modes of the FACTS devices and each plant can be configured appropriately for the volume of electricity it sends out. The researchers suggested an OPF-based market clearing algorithm which contains limitations on voltage stability in [8]. FACTS devices will boost the power system protection with the right control objective [9]. The OPF program reduces the objective function of pre and post contingency while respecting all the constraints of the system [10]. FACTS devices improve the static safety of a particular system and reduce the power loss [11].

In the event of an emergency, it is first to identify those emergency cases that cause loss of load or generation or insulation, in order to assess whether a de-regulated power system can remain safe and reliable in operational condition. Based on experience gained by the system operators, a degree of severity is assigned to each quantity after the contingency according to potential damage which could be imposed upon the power system by quantity [12].

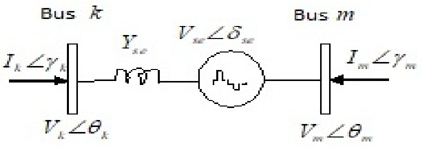
FACTS systems are one technology that eliminates congestion and enables the most efficient possible use of the present electrical grid transportation systems and many other advantages, in particular FACTS series devices, such as SSSC. The SSSC device can control active and reactive transmission line power flows simultaneously [13-15]. No discussion on the desired SSSC settings for an OPF solution, as well as the impact on the operating and reactive power flow control has so far taken place despite the various static effects of SSSC [16-17].

Complete system modelling using flow equations and operational constraints is essential in order to prevent any limit breaches from occurring, which is necessary for the protection of the system's operation [18]. A change in the line-flow pattern will also be implemented in addition to the rescheduled generation. This change will be brought about by modifying the line flow control of the series Facts devices. In [19], a control technique was presented for decreasing line overload on electrical systems by using FACTS controllers. This approach was included in the article.

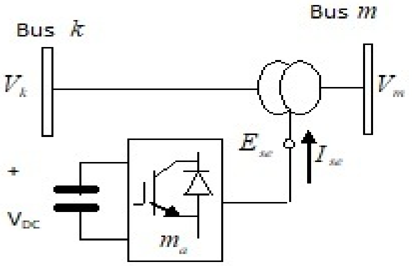
This paper presents an excellent SSSC power flow to alleviate overloads and congestion through optimal configuration of all controllable variables under selected network contingency conditions for a static power system load. This was accomplished by minimising the impact of potential network overloads and congestion. The recommended approach is shown by simulated results obtained from the revised IEEE 14 bus testing system.

2. EQUIVALENT CIRCUIT OF SSSC

In an SSSC, a capacitor, an inverter and a coupling transformer are usually included. In order, SSSC is connected via a coupling transformer with transmission line. The SSSC has a feature like the permanent static phase shifter in the continuous operation and injects quadrature voltage into one of the final voltages to regulate the active energy flow. The SSSC is, however, much more powerful than a phase shifter and its very own reactive power supplies as a capacitor, due to its lack of reactive power from the AC system. The SSSC can adjust the power flow as well as nodal voltage. The schematics of the SSSC and its equivalent circuit are shown in Figures 1(a) and (b).



(a)



(b)

Figure 1: (a) Equivalent circuit (b) Schematic

The SSSC serial voltage source can be displayed by

$$E_{se} = V_{se}(\cos\delta_{se} + j\sin\delta_{se}) \tag{1}$$

To achieve the desired levels of active and reactive power flows through the SSSC, the magnitude and phase angle of the SSSC model must be regulated. This may be done using any iterative approach that is appropriate. There are upper and lower bounds for the amplitude of the voltage, which is determined by the rate at which the SSSC capacitor discharges; the phase angle of the voltage may be anywhere from 0 to 2π radians.

The real flow constraint is stated as

$$P_{ji} - P_{ji}^{specified} = 0 \tag{2}$$

where

$P_{ji}^{specified}$ = specified active power flow

The reactive power flow constraint can be given as

$$Q_{ji} - Q_{ji}^{specified} = 0 \tag{3}$$

where

$Q_{ji}^{specified}$ = specified reactive power flow

The voltage limitations of the equivalent voltage are given as

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \tag{4}$$

$$\delta_{se}^{\min} \le \delta_{se} \le \delta_{se}^{\max} \tag{5}$$

3. HYBRID IPM-EPSO ALGORITHM

For difficult optimization problems, the Interior Point Method (IPM) may search for non-linear and discontinuous function solutions. On the other hand, slow convergence is often marked by a value that is almost as good as the best one, and the solution may stay in the local region. The proposed algorithm integrates the primary benefits of two different approaches suitably. To begin with, IPM is used in the first randomly created population in order to carry out the process of global exploitation. This provides an excellent beginning point for the evolutionary component of swarm optimization (EPSO). The combined solution is always superior to all other approaches, may be used independently, and reduces the amount of time required on the computer as a result of the complimentary qualities of IPM and EPSO.

Figure 2 is an illustration of the concept of a recommended two-layer optimization strategy. While Layer 1 generates the initial solutions via the use of random IPM, Layer 2 is in charge of optimising the EPSO system in order to get the optimal output variables.

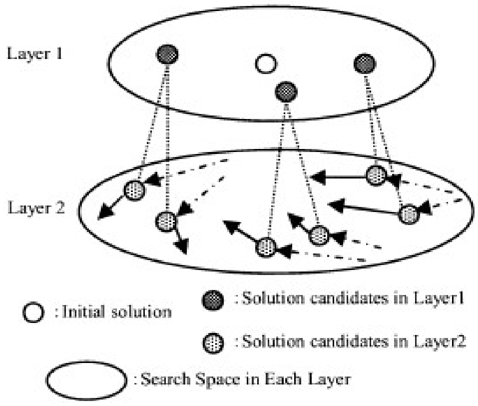


Figure 2: Concept of proposed method

Miranda et al. [20] created EPSO, which is an optimization method that combines the conventional PSO with the evolutionary approach. Either an evolving PSO weight or an evolving PSO motion law algorithm could be appropriate ways to think about it. EPSO has previously shown its effectiveness, accuracy, and resilience, which enables it to be used for challenges involving power systems.

EPSO may be thought of as a hybrid approach for the formulation of strategies and the optimization of procedures based on the use of a particle swarm. The EPSO algorithm is presented in the following form: Think about the number of different solutions or particles involved in the current iteration. The EPSO's general plans consist of the following, as listed below:

REPLICATION: R times for each particle that was duplicated in this experiment.

MUTATION: Each granule brings about a different strategic parameter change.

REPRODUCTION: In accordance with the law of particulate motion, each particle that undergoes a mutation gives rise to a descendent.

EVALUATION: the offspring's fitness is evaluated individually.

SELECTION: Either by a random tournament or some other kind of selection, only the most robust particles are allowed to reproduce and form a new generation.

A new particle results as

$$s_i^{new} = s_i + v_i^{new} \tag{6}$$

$$v_i^{k+1} = w_{i0}^* v_i^k + w_{i1}^*\left(pbest_i - s_i^k\right) + w_{i1}^*\left(gbest^* - s_i^k\right) \tag{7}$$

Up until this point, it seems as if this is the PSO; it still has its inertia, memory, and cooperation criteria. However, weights are adjusted according to the specifications

$$w_{ik}^* = w_{ik} + \tau.N(0,1) \tag{8}$$

Where, N (0, 1) represents a random variable with a Gaussian distribution, with a mean of 0 and a variance of 1. The following equation introduces a random element that disrupts the global best (*gbest*)

$$gbest^* = gbest + \tau'.N(0,1) \tag{9}$$

Learning is governed by these τ, τ' factors (either predetermined or taken into consideration as strategic criteria, and are open to alterations). Because this system benefits from two "pushes" in the right directions, namely the Darwinist selection and the particle movement rule, it is only natural to anticipate that it will have favourable convergent qualities when compared with ES or PSO. This is because the system benefits from two "pushes" in the right directions. Additionally, EPSO may be classed as both a self-adapting algorithm and a self-learning algorithm. This is due to the fact that, similar to other development methods, it depends on the mutation and selection of strategic parameters in order to function.

4. MATHEMATICAL FORMULATION OF OPF PROBLEM

The The conventional formulation of the problem of optimal power flow determines the perfection of control variables such as real power generation, terminal generation voltages,

transformer tap adjustment, and shunt compensation while minimising objective functionalities such as generated system costs, active power losses, and a total severity index. This is accomplished by perfecting the control of variables such as real power generation. The main objective is to achieve the greatest possible level of social security (or to minimise the generation cost if loads are inelastic). The objective of the central distributor is to optimise the total social welfare while adhering to the criteria of both operations and security [21-25]. This is accomplished by efficiently dispatching generators into a centralised pool-based market.
The problem is stated mathematically as

Objective Function -1 (OF-1): f_1= Social welfare maximization

Objective Function -2 (OF-2): f_2 = Weighted multifunction

Objective Function -3 (OF-3): f_3= Weighted multifunction

where

$$f_1 = F_1 \tag{10}$$

$$f_2 = w_1 * F_1 + w_2 * F_2 \tag{11}$$

$$f_3 = w_1 * F_1 + w_2 * F_3 \tag{12}$$

and $w_1 + w_2 = 1$

F1= SW = Social Welfare = - ($Cd * Pd$ - $Cs * Ps$) = $(\sum_{i=1}^{N_G} C_{Gi}(P_G) - \sum_{i=1}^{N_D} B_{Di}(P_D))$ (13)

F2 = Active power loss=

$$\sum_{i=1}^{NL} G_{ij}(V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)) \tag{14}$$

F3 = Composite Logic Criteria (CLC) = (Total Index$_{LL}$+Total Index$_{VP}$+Total Index$_{VSI}$) (15)
where
CLC: Composite Logic Criteria
TI$_{LL}$: Total Index of Line Loadings
TI$_{VP}$: Total Index of Voltage Profiles
TI$_{VSI}$: Total Index of Voltage Stability Indices
Subject to the following constraints:

(a) *Power flow equations*

$$Ps_i - Pd_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}),$$
$$i = 1,...nb \tag{16}$$

$$Qs_i - Qd_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij})$$
$$i = 1,...nb \tag{17}$$

(b) *Supply and demand bids blocks*

$$Ps_{i,\min} \le Ps_i \le Ps_{i,\max}, \quad i = 1,...nb \tag{18}$$

$$Pd_{i,\min} \le Pd_i \le Pd_{i,\max}, \quad i = 1,...nb \tag{19}$$

(c) *Generation reactive power limits*

$$Qg_{i,\min} \le Qg_i \le Qg_{i,\max}, \quad i = 1,...ng \tag{20}$$

(d) *Voltage limits*

$$V_{i,\min} \le V_i \le V_{i,\max} \qquad i = ng + 1,...nb \tag{21}$$

$$-\pi/2 \le \delta_i \le \pi/2, \qquad i = 1,...nb \tag{22}$$

(e) *Apparent line flow limit*

$$|S_{ij}(\theta, V)| \le S_{ij}^{\max}, i = 1,...nb, j = 1,...nb \tag{23}$$

(f) *Voltage stability limit*

$$L_j < L_j^{\max}, \qquad j = g + 1,...,nb \tag{24}$$

(g) *SSSC Voltage and angle limits*

$$V_{se,\min} \le V_{se} \le V_{se,\max} \qquad i = ng + 1,...nb \tag{25}$$

$$0 \le \delta_{se} \le 2\pi, \qquad i = 1,...nb \tag{26}$$

where ng and nb are the number of generators and buses respectively, $C_{Gi}(P_{Gi})$ is the cost curve of ith generator, $B_{Di}(P_D)$ is the bid curve of ith generator, $V_{i,\min}$, $V_{i,\max}$ are minimum and maximum voltage limits at bus-i, S_{ij} is the apparent power flow in transmission line connecting nodes i and j, and $S_{ij}^{\max}$ is its maximum limit, P_{Gi} and Q_{Gi} are the active and reactive power generation at node i, P_{Di} and Q_{Di} are the active and reactive power load at node i, P_i and Q_i are the net active and reactive power injection at node i. , $Vse_{\min}$, $Vse_{\max}$ the minimum and maximum limits of series voltage source of SSSC , and

$\delta se_{\min}$, $\delta se_{\max}$ are the minimum and maximum limits of series voltage source angle of SSSC .

4.1 Comprehensive computer process for problem solving

The IPM EPSO algorithm that has been suggested may have its implementation stages outlined further down.

Step 1: In the first step of the power flow analysis procedure, data must be entered.

Step 2: Execute the load flow according to the specified contingency in the second step

Step 3: Assess the gravity of the situation using a composite logic criteria-based strategy for dealing with network contingencies.

Step 4: Repeat Steps Two and Three for Each Line of Transformation

Step 5: Based on the parameters established by the composite logic severity index, choose the contingencies that pose the greatest threat to the network.

Step 6(a): Select an SSSC and its position inside the system as the next step (6a).

Step 6(b): In step 6b, you will generate Gen = 0, then configure the IPM-EPSO simulation settings, and last, you will randomly initialise and store k people on the archive inside their respective borders.

Step 7: Carry out the load flow based on the contingency that has been chosen for each person in the archive. This will allow you to determine the voltages and angles of the load bus, as well as the load bus voltage stability indices, generator reactive output, and line power flow calculations.

Step 8: Evaluation of the functions of the penalty is the eighth step.

Step 9: Step 9 involves determining both the individual's objective fitness values as well as their own respective fitness values.

Step 10: The tenth step is to locate and save the finest xglobal and xlocal values.

Step 11: Improve the generation counter such that it reads Gen = Gen+1.

Step 12: Applying IPM EPSO to operators in order to produce k new individuals constitutes step 12.

Step 13: Step 13 entails operating the power flow to take readings of the bus voltages, angles, stability indicators for load bus voltage, reactive power outputs for generators, and line flows for each new individual added to the archive.

Step 14: Evaluation of the penalty functions is the fourteenth step.

Step 15: The next step, number 15, is to evaluate the physical potential of each new objective function value.

Step 16: Apply and then update the IPM-EPSO Selection Operator. This concludes step 16.

Step 17: Update and save the optimal xglobal xlocal configuration. This concludes step 17.

Step 18: If one of the requirements for stopping the process is not met, go to stage 18, which is to repeat stages 7-17. The other approach is to stop at number 19.

Step 19: Printing the findings is the 19th stage.

5. RESULTS AND DISCUSSIONS

This section presents the study details on IEEE test systems. This work uses a modified 14-bus IEEE test system [26]. There are 14 buses in the IEEE 14-bus system, five of which generator buses. Bus 1 is a slack bus, PV bus 2, 3, 6 and 8 and rest are PQ buses. A total of 259.0 MW and 73.5 MVAR are loaded in the system, of which tap changing transformers are 3, 20 branches and 17 are lines. Shunt compensation for the voltage control is assumed to be available for buses 9 and 14. There are 10 variables, which comprise five are voltages of the PV generator, three transformers changing the tap and two shunt compensators.

The generators were considered GENCOS and the loads were considered DISCOS/ESCOS to simulate competitive market structures. In every case, individual entities are assumed to be separately operated. There has been one SSSC unit in line 8-6, which proved to be the best location for congestion reduction. The actual and reactive power flow specified in line 8-6 varies continually between the real and reactive power flow limits of the line. SSSC control variables are real and reactive power values. SSSC limits were $P_{mk}^{\min}$ =0.0, $P_{mk}^{\max}$ =0.45, $Q_{mk}^{\min}$ =0.0, and $Q_{mk}^{\max}$ =0.1 p.u. For minimization of the objective functions by using proposed method IPM-EPSO, three objective functions are considered.

The proposed IPM-EPSO hybrid algorithm was tested in the most extreme network contingency to resolve the optimized power flow problem. For minimization with the proposed algorithms, three objective functions are considered.

The convergence characteristics of different objective functions under the top contingency line 2-3 are seen in figures 3-7 with and without SSSC categories. It can be seen from Figs. 3-7 that the objective functions 1, 2 & 3 converged within 50 iterations to their minimal value.

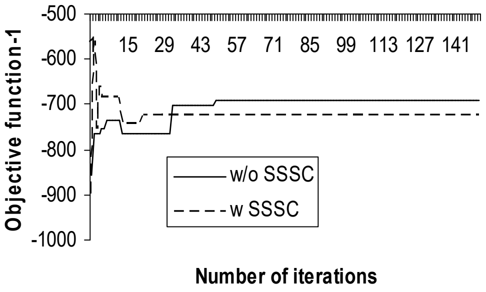


Figure 3: Convergence of OF-1

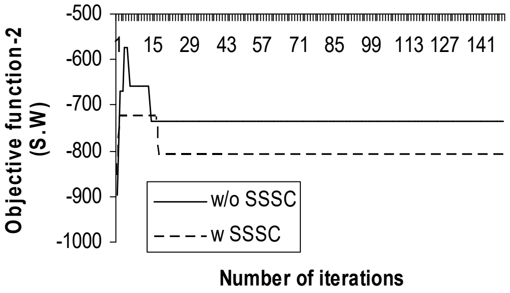


Figure 4: Convergence of OF- 2 (S.W)

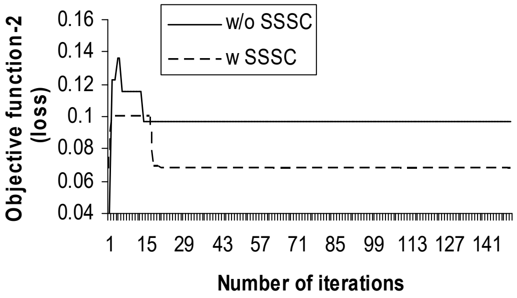


Figure 5: Convergence of OF- 2 (loss)

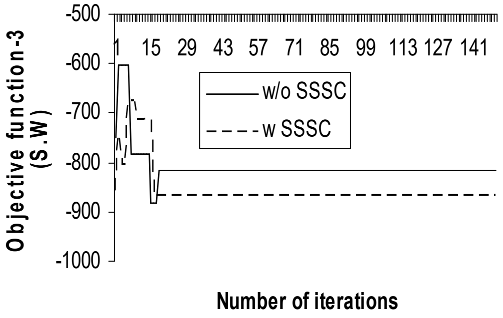


Figure 6: Convergence of OF- 3 (S.W)

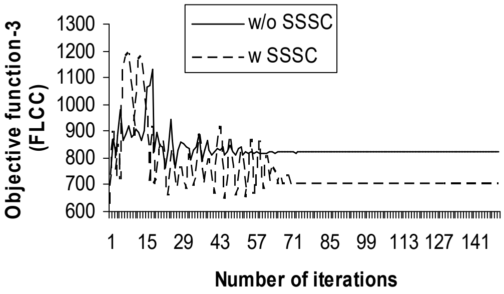


Figure 7: Covergence of OF-3 (CLC)

The comparison of line loads, with and without SSSC, with three target functions, is presented in Figures 8-10. For all the objectives of line 2-3 contingency, efficiency can be observed from the respective figures. Figures 11-16 shows superiority of the proposed IPM-EPSO based OPF algorithm and the SSSC with respect to good load bus voltages profiles and voltage stability indices in limits.

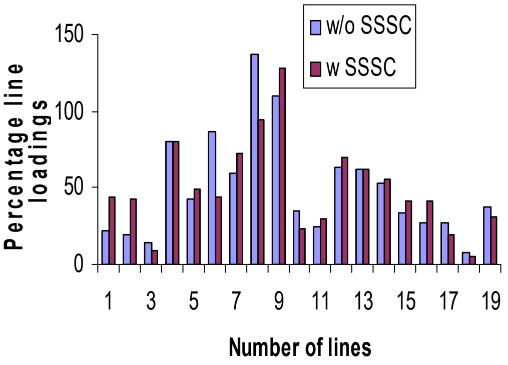


Figure 8: Line loadings (OF -1)

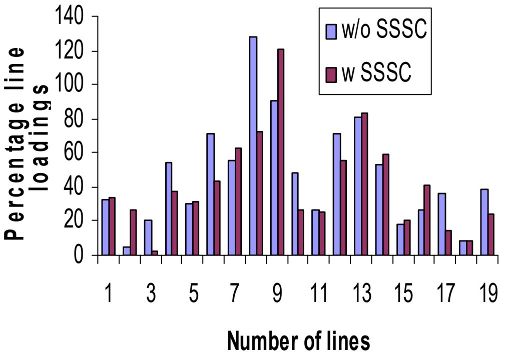


Figure 9: Line loadings (OF -2)

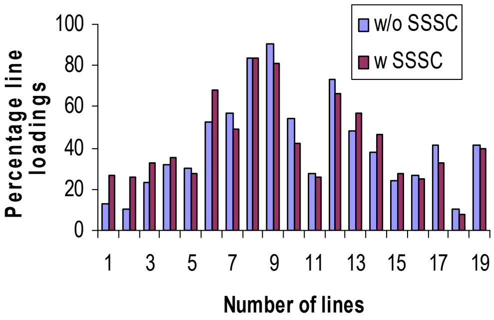


Figure 10: Line loadings (OF -3)

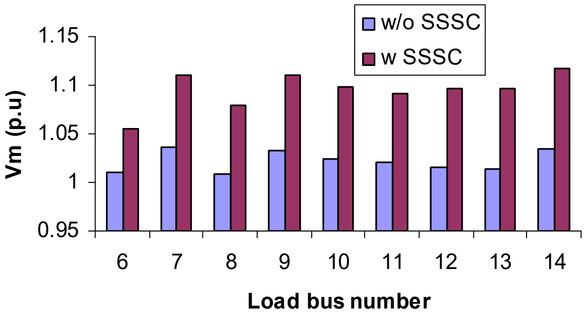


Figure 11: Load bus voltage profiles (OF -1)

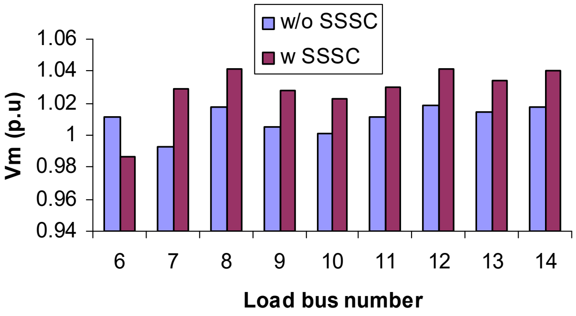


Figure 12: Load bus voltage profiles (OF -2)

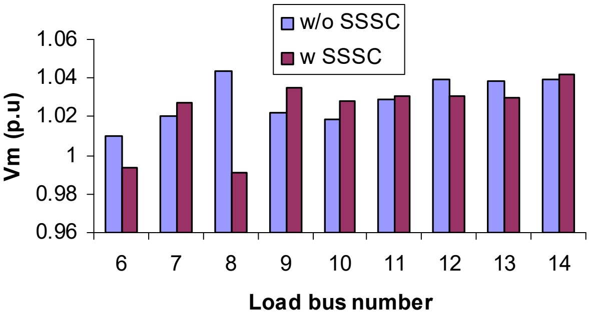


Figure 13: Load bus voltage profiles (OF -3)

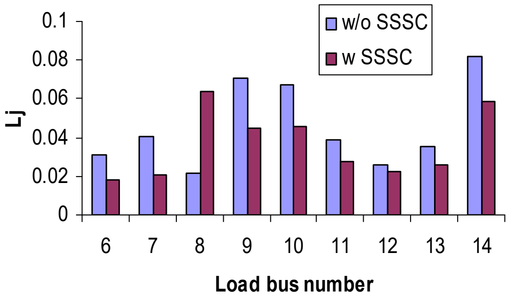


Figure 14: Voltage stability indices (OF -1)

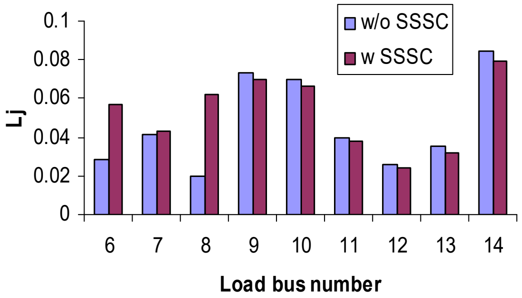


Figure 15: Voltage stability indices (OF -2)

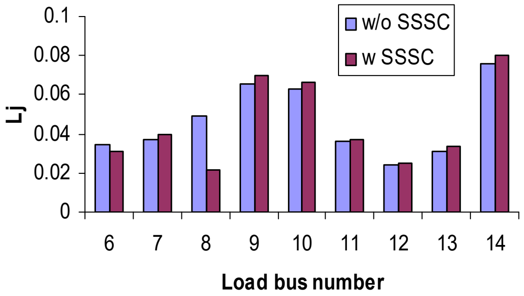


Figure 16: Voltage stability indices (OF -3)

Table 1 provides a listing of the values that were produced from the optimum flow solution when it was applied to the high contingency for the different control variables and performance metrics. Table 1 demonstrates that all of the control variables are maintained within their limits while simultaneously reducing the amount of the target function that was defined. The ideal values of actual power loads are shown in Table 2 (the loads shown reflect the elastic loads), which indicates that both the maximum and lowest power loads are also maintained.

The case studies with all three objectives are compared with and without SSSC under the highest circumstances. Tables 1 show the results from the simulation while minimizing various target functions. It is obvious from Table 1 that the proposed hybrid SSSC-based OPF, IPM-EPSO algorithm is able to minimize the objective function specified, such as to maximize social welfare and improve network security. The IPM-EPSO method that has been developed demonstrates that the optimum solutions are accessible not only for multiple objective functions, but also for weighted sum multi-objective functions taken from Table 1. The placement of the SSSC in line 8-6 is a good way of improving system safety in a deregulated environment.

Table 1: Optimal settings of control variables

Control variable (p.u)	Limits		Base case (under contingency)	OF					
				OF 1		OF 2		OF 3	
	Min	Max		Without SSSC	With SSSC	Without SSSC	With SSSC	Without SSSC	With SSSC
P_{G1}	0	3.40	1.1695	1.2734	1.2829	0.9987	0.8376	0.6495	0.7918
P_{G2}	0	0.70	0.7000	0.4006	0.2174	0.2126	0.3122	0.3431	0.3802
P_{G3}	0	0.80	0.2809	0.3159	0.4110	0.1600	0.5069	0.5975	0.5483
P_{G4}	0	0.90	0.2632	0.4259	0.4526	0.6888	0.4572	0.7418	0.5590
P_{G5}	0	0.70	0.2726	0.4005	0.2884	0.5236	0.4677	0.3163	0.3474
V_{G1}	0.95	1.10	1.0700	0.9973	1.0364	1.0251	1.0409	0.9924	0.9757
V_{G2}	0.95	1.10	1.0589	1.0207	1.0836	0.9730	1.0214	1.0202	0.9880
V_{G3}	0.95	1.10	1.0309	1.0279	1.0892	1.0151	1.0320	1.0682	1.0348
V_{G4}	0.95	1.10	1.0492	1.0282	1.0933	1.0168	1.0532	1.0414	1.0441
V_{G5}	0.95	1.10	1.0241	1.0261	1.0747	0.9744	1.0829	1.0208	1.0547
Tap-1	0.9	1.1	1.0182	0.9700	0.9000	1.0500	0.9900	0.9900	1.0000
Tap-2	0.9	1.1	0.9174	0.9700	0.9400	0.9800	1.0200	1.0200	0.9000
Tap-3	0.9	1.1	1.0187	0.9700	1.0500	1.0800	0.9500	1.0400	0.9600
Q_{SH-9}	0	0.2	0	0.1200	0.0600	0.0600	0.0600	0	0.1200
Q_{SH-14}	0	0.2	0	0.1200	0.1200	0.1200	0	0.0600	0.1200
P-loss (p.u)			0.0952	0.1284	0.0971	0.0966	0.0678	0.0757	0.0611
S.W. ($/hr)(F1)			-717.5252	-690.1192	-724.6858	-733.5791	-810.1196	-817.9368	-865.9544
TI_{LL}			419.116	435.0281	356.2	369.4832	306.2496	255.4679	212.5
TI_{VP}			631.407	456.5691	900	324	538.1681	529.3945	453.1884
TI_{VSI}			36.1539	36.1539	36.2	36.1539	36.1539	36.1539	36.1539
CLC			1086.700	927.7511	1292.4	729.6372	880.5717	821.0164	701.8423
V_{Se}			-	-	0.0845	-	0.0876	-	0.0630
θ_{Se}			-	-	-87.914^0	-	-42.1^0	-	-59.255^0

Table 2: Optimal real power load levels (p.u)

Load Bus power	Limits		OF					
			OF 1		OF 2		OF 3	
	Min	Max	W/O SSSC	With SSSC	W/O SSSC	With SSSC	W/O SSSC	With SSSC
P_{L1}	0	0	0	0	0	0	0	0
P_{L2}	0.1845	0.2495	0.2079	0.2243	0.2271	0.2197	0.1950	0.2017
P_{L3}	0.8007	1.0833	1.0506	0.8919	0.8933	0.8393	0.9473	0.9612
P_{L4}	0.0952	0.1288	0.1056	0.1020	0.1056	0.1199	0.1020	0.1109
P_{L5}	0	0	0	0	0	0	0	0
P_{L6}	0.4063	0.5497	0.4788	0.4903	0.4063	0.5046	0.4982	0.4633
P_{L7}	0	0	0	0	0	0	0	0
P_{L8}	0.0646	0.0874	0.0709	0.0750	0.0763	0.0818	0.0772	0.0708
P_{L9}	0.2507	0.3393	0.3002	0.2801	0.2940	0.2789	0.2858	0.2939
P_{L10}	0.0765	0.1035	0.0887	0.1000	0.0921	0.0931	0.0864	0.0844
P_{L11}	0.0298	0.0402	0.0339	0.0353	0.0358	0.0321	0.0355	0.0328
P_{L12}	0.0527	0.0713	0.0593	0.0655	0.0585	0.0555	0.0630	0.0625
P_{L13}	0.1148	0.1553	0.1443	0.1395	0.1429	0.1375	0.1354	0.1325
P_{L14}	0.1266	0.1713	0.1477	0.1514	0.1553	0.1513	0.1467	0.1517
TTL			2.6879	2.5553	2.4872	2.5137	2.5725	2.5657

Table 3: Number of lines/buses under different severity categories

Contingency	OF		Line Loadings				Bus Voltage Profiles			Bus Voltage Stability Indices				
			LS	BS	AS	MS	BS	AS	MS	VLS	LS	BS	AS	MS
2-3	Before Optimization		12	3	2	2	0	3	6	9	0	0	0	0
	OF 1	Without SSSC	11	5	1	2	0	6	3	9	0	0	0	0
		With SSSC	12	5	1	1	0	0	9	9	0	0	0	0
	OF 2	Without SSSC	11	6	1	1	0	9	0	9	0	0	0	0
		With SSSC	13	5	0	1	0	5	4	9	0	0	0	0
	OF 3	Without SSSC	13	5	1	0	0	5	4	9	0	0	0	0
		With SSSC	14	5	0	0	0	7	2	9	0	0	0	0

VLS: Very Low Severe, LS: Less Severe, BS: Below Severe, AS: Above Severe, MS: Most Severe

Table 3 provides the line and bus descriptions for each of the four severity levels. During the process of minimising objective function 3, using a severity index based on Composite Logic Criteria, in the weighted total of the multifunction, the number of buses that fit into the most severe category was reduced. Therefore, the weighted sum multi-objective function that involves the CLC severity index is a powerful option that may effectively maximise societal welfare without sacrificing safety.

6. CONCLUSIONS

This article proposes a new way of operating deregulated power systems to maintain system safety, with special emphasis on voltage stability. The IPM-EPSO method has been used to resolve a multi-objective social benefit optimal power flow problem, maintaining network security. The line overload is reduced, losses are reduced and the system safety is increased due to the reshuffling of the generator output. In the modified 14-bus IEEE network, the efficiency of the suggested solution was demonstrated.

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