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ARTIFICIAL INTELLIGENCE APPLICATION TO MAXIMIZE SOCIAL WELFARE IN THE ELECTRICITY MARKET BY INSTALLING SSSC

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ABSTRACT

Congestion leads to a decrease in social welfare in a competitive electricity market. Social Welfare Maximization is thus an independent operator's technical challenge (ISO). The congestion can be eliminated by increasing the transmitting power of a network. The Static Synchronous Series Capacitor (SSSC) is very useful in optimizing the operation of the transmission system by being able to directly control the power flow. A corrective solution has been proposed in this paper to congestion management by SSSC. The Interior Point Approach Integrated with the Evolutionary Particle Swarm Optimization (IPM-EPSO) is recommended for congestion control to optimize social welfare. For checking congestion reduction Fuzzy logic has been used. IEEE 30-bus system tests the proposed methodology. The findings evaluated with and without SSSC indicate that this system is appropriate for long-term congestion management

Keywords: *Management of congestions; Deregulated power system; SSSC; Social Welfare; IPM-EPSO*

1. INTRODUCTION

Due to rapid technological advances, electrical energy consumption is steadily increasing. Many electrical utilities have been forced over the last three decades to change their way of doing business from monopoly to competitive market structure. Pilot steps are being implemented in India to implement the electricity market and the country is moving on to a competitive electricity market. The primary aim of deregulation is to make supply and demand more efficient so that all actors, i.e. generation firms, distribution companies, and consumers, can optimize their wellbeing. The lowest price agreed for providing a certain volume of electricity by a power generator firm is the offering. Likewise, the market or benefit offer of the user is the highest price charged for a given power supply consumption. The ISO is responsible for the acquisition and sale, based on supply and requirements for customers of electricity between generator and distributor companies, which are prepared to maximize social welfare. Transmission improvements are used to solve the problem, subject to system security constraints, to achieve minimum generation costs. On the other hand, the aim is to optimize social security in most experiments on deregulated power structures. Several research on control of congestion to optimize social welfare have also been carried out[1-2], and the maximization of social welfare in a de-regulated world concerning reactive power and congestion[3]. Distributed generator sites are presented in [4] to optimize social welfare. The research focused on a way to enhance social welfare in transmission networks with congestion probabilities.

FACTS [5] has also been used to resolve the problem of congestion and maximize social welfare. Many studies on improving existing power grids via an optimal FACTS location have been proposed [6-19]. For system expansion with UPFC, the internal dot method was used to maximize social welfare and congestion management [20]. In [21], non-linear Mixed Integer programming was used to optimize FACTS location to maximize multi-time social welfare. But the impact on reactive power flow of FACTS was ignored. FACTS is ideally suited for congestion management by using genetic algorithms (GA and GWO algorithms) to maximize the welfare of people with a thyristor-controlled series capacitor. Efficient GA to optimize the size and position of TCSC in a deregulated congestion management market was proposed [23] to maximize social welfare costs. In a double-sided market for auctions, the new fumigation-based genetic algorithm (Fuzzy-GA) is used to reduce congestion and maximize social benefits by locating and sizing one TCSC unit [24].In [25] the GA was proposed for optimum congestion management to increase the social welfare, location, and size of this device. In[26] a new, effective differential evaluation social welfare programming technique has been introduced, based on contingency analysis, by optimally positioning various FACTS equipment on the pool electricity market. Congestion management based on sensitivity is described in [27] with FACTS controls optimally placed. The congestion control, using an IPFC, is carried out in [27]. In the context of deregulated electricity markets, the application of a series FACTS for congestion management is discussed [28].

This article proposes an IPM-EPSO based on Fuzzy, which maximizes social advantages and reduces congestion through the use of SSSC. The influence of the SSSC on the updated IEEE 30-bus social welfare research framework will be tested in simulations. The approach suggested highlights the benefits of SSSC in the deregulated energy market and how the ISO can strengthen social welfare and avoid congestion in the grid.

2. COMPOSITE LOGIC CRITERIA

It The Fuzzy set theory was proposed by Prof. L.A. Zadeh in 1965 as a mathematical concept. Fuzzy logic is a logic that uses graded or quantified statements instead of purely true and false statements. The fuzzy set of linguistic variables allows objects with membership ratings between 0 and 1. Intervals are established based on pre/post contingent amounts for fuzzification of cognitive elements. The input and output membership functions are selected based on the assignment of pre/post-dependent quantities. The pre/post-dependent quantity is first defined in a fuzzy notation before the fuzzy logic rules can be processed.

As seen in table 1, of loading line (LL) is divided into four groups utilizing a fuzzy set of notes.

Table 1 Fuzzy set notations for line loadings

Percentage Line Loading	0-50%	51-85%	86-100%	Above 100%
Linguistic Variable	Loaded Lightly (LL)	Loaded Usually (LU)	Completely Loaded (CL)	Loaded Over (LO)
Severity Membership Function	Low Severe (LS)	Under Severe (US)	Severe Above (SA)	Higher Severity (HS)

After obtaining the intensity indexes of all the lines, the cumulative index (Total IndexLL) is obtained for a given line output using the following expression.

$$Total\ Index_{LL} = \sum w_{LL}\ SI_{LL} \quad (1)$$

where w_{LL} = Coefficient of weighting,

SI_{LL} = Index of intensity

The severity index weighting coefficients used are

w_{LL} = 0.25 for LS, 0.50 for US, 0.75 for SA and 1.00 for HS

The result was that the overall index was predominantly governed by a fourth index (HS).

Each bus voltage profile (VP) is split into three categories using fuzzy set notes, as shown in Table 2.

Table 2 Fuzzy set notations for voltage profiles

Voltage Profile (p.u)	Below 0.9	0.9 to 1.02	Above 1.02
Linguistic Variable	Low Voltage (LV)	Normal Voltage (NV)	Over Voltage (OV)
Severity Membership Function	Under Severe (US)	Severe Above (SA)	Higher Severity (HS)

When choosing extreme indices for all voltage profiles, the Total Index$_{VP}$ of the bus voltage profiles for a specific line outage is obtained by using the following expression.

$$\text{Total Index}_{\text{VP}} = \sum w_{VP}\ SI_{VP} \qquad (2)$$

The severity index weighting coefficients used are

$w_{VP} = 0.30$ for US, 0.60 for SA and 1.00 for HS

As seen in Table 3, every VSI is divided into five groups with fuzzy set comments.

Table 3 Fuzzy set notations for voltage stability indices

Voltage Stability Index Value	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0
Linguistic Variable	Very Low Index (VLI)	Low Index (LI)	Medium Index (MI)	High Index (HI)	Very High Index (VHI)
Severity Membership Function	Very Low Severe (VLS)	Low Severe (LS)	Under Severe (US)	Severe Above (SA)	Higher Severity (HS)

Using this expression, the Total IndexVSI of the Bus Voltage Stability Index is obtained after obtaining the severity indices of all the voltage stability indices

$$\text{Total Index}_{\text{VSI}} = \sum w_{VSI}\ SI_{VSI} \qquad (3)$$

The weighting coefficients used for the severity indices are

$w_{VSI} = 0.20$ for VLS, 0.40 for LS, 0.60 for US,

0.80 for SA and 1.00 for HS

where

w_{VSI} = Coefficient of weighting ,

SI_{VSI} = Pre/post contingent quantity severity index

A composite logic criteria method run in parallel is used to achieve the cumulative composite logic criteria table, as seen in Figure 1, for pre/post-contingency operational conditions. The Composite Logic Criteria (CLC) index is designed for determining a cumulative severity index for line loading, voltage profiles, and stability indices.

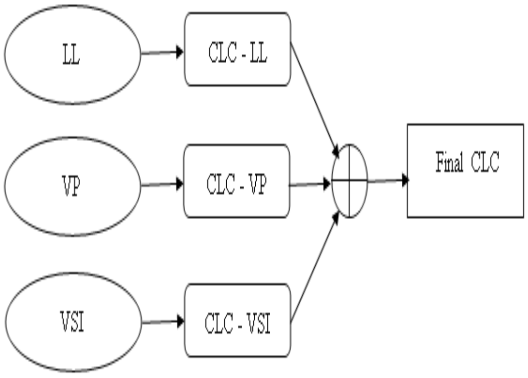

Figure 1 Parallel Operated Composite Logic Criteria System

3. STATIC SYNCHRONOUS SERIES COMPENSATOR

Emerging systems of electricity often lead to situations in which the system does not exist in a safe operating area due to increased loading or severe contingencies. In these situations, the operator's primary objective is to implement control measures to bring the power system to a safe area. FACTS equipment may play an important role in improving the safety of the power grid.

The SSSC is a coupling transformer, inverter, and capacitor, as seen in Figure 2. The SSSC is connected serially with a transmission line by the coupling transformer. The SSSC produces and inserts a voltage sequence that can be regulated to adjust the impedance of the transmission line. The power flow of the line connected to the SSSC is thus regulated.

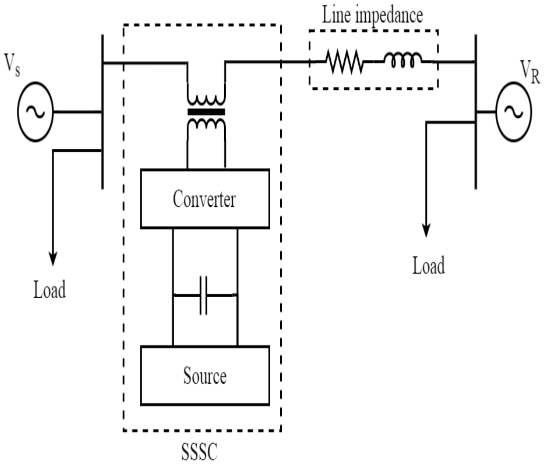

Figure 2 Typical Sssc Scheme

The SSSC provides a capacitive or inductive compensating voltage to its current specified rating, independent of the line current. The realistic minimal line current is that the SSSC can also consume true power from the line to replenish its losses. The VA rating of the SSSC represents the maximum line current and the maximum voltage compensation.

The condenser is reactive impedance in series with the thread. Thus, the voltage above it is equal to the line current that depends on the transmission angle. As the transmission angle increases, the compensatory voltage often changes (and line current). The power transmission P is a parametric function for compensating sequence s (s = X_C/X_L), that is [29],

$$\text{Transmitted Power (P)} = \frac{V^2}{X_L(1-a)} \sin\alpha \quad (4)$$

Regardless of the line current, the SSSC injects the compensating voltage into the line. The transmitted power P thus becomes an injected voltage parameter and can be expressed as follows

$$P_q = \frac{V^2}{X_L}\sin\delta + \frac{V}{X_L}V_q\cos(\delta/2) \qquad (5)$$

The series capacitor boosts transmitting power by a fixed percentage of that transferred on a given δ by a non-compensated line. The SSSC has to keep the maximum classified capacitive or offsetting reactance at every line current until the maximum rate is established in impedance compensation mode. For practical use, I_{max} may be separately defined for the maximum rated line current and a specified short duration over current for variable impedance type compensators. For these currents and the relevant maximum voltages, the basic VA rating of the major power components of the SSSC must be assessed. Despite the way that a fixed capacitor produces a compensative voltage proportionally to the line current, a controllable offset voltage range of the overall compensator also, to a certain extent, becomes a function of this compensation system in terms of main components (conversion and fixed-capacity) ratings and operational losses.

4. HYBRID IPM-EPSO ALGORITHM

The Interior Point Method (IPM) can look for non-linear and discontinuous function solutions for optimization challenges. However, the slow convergence is often characterized by the almost optimum value and the solution can stay with the local area. The suggested algorithm combines two methods' main advantages accordingly. First of all, IPM is used in the randomly generated initial population to perform global exploitation. This gives evolutionary particle swarm optimization a good starting point (EPSO). The hybrid solution also goes beyond one method, operates only but decreases the total computation time because of its complementary IPM and EPSO properties.

Figure 3 shows the concept of a proposed method based on the two-layer optimization, wherein Layer 1 the initial solutions are randomly generated by the IPM, layer 2 is responsible for optimizing the optimum output variables by the EPSO system.

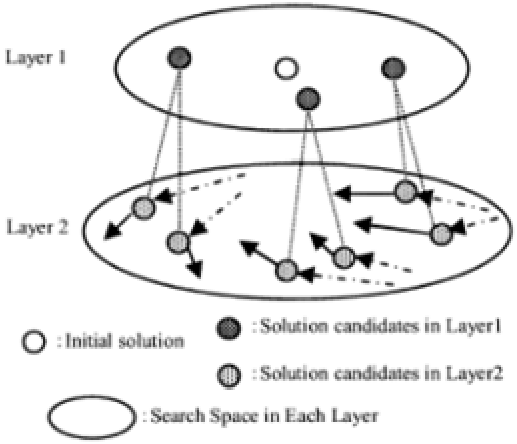

Figure 3 Concept Of Proposed IPM-EPSO

Miranda et al.[30] developed EPSO, combining conventional PSO and evolutionary strategy. It can be regarded either as an evolving PSO weight or as an evolving algorithm with a PSO motion rule. EPSO has already demonstrated its effectiveness, precision, and robustness, which makes it applicable to problems in power systems.

EPSO can be viewed as a hybrid process for the development of strategies and optimization of particle swarm methods. The following is the EPSO algorithm. Consider several solutions or particles in a given iteration. The following are the general plans of the EPSO:

- REPLICATION: Replicated R times for each particle
- MUTATION: Strategic parameters of each particle changes
- REPRODUCTION: Each particle mutated produces descendants according to the rule of particulate motion.

- EVALUATION: fitness assessed for each offspring.
- SELECTION: The best particles survive to form a new generation by the stochastic tournament or by other selection processes.

A new particle results as

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

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

So far, this appears to be the PSO—it retains its inertia, memory and cooperation conditions. However, weights change as specified

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

Where N (0, 1) is the Gaussian distribution random variable, the mean 0 and variance 1. The next equation randomly disturbs the global best (gbest)

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

The τ, τ' is parameters for learning. They are also strategic parameters and are therefore subject to mutation.

It is therefore only natural that it should be expected to have favorable convergent qualities when compared with EP or PSO because this system benefits from two "pushes" in the right directions, the Darwinist selection, and the particle movement rule. Moreover, EPSO can also be categorized as an algorithm that can adapt itself, because it relies just like all development strategies on the mutation and selection of strategic parameters.

5. MATHEMATICAL FORMULATION OF OPF PROBLEM

The standard formula of an optimum power flow problem specifies the perfection of control variables, such as true power generation, terminal power, tap-changing, shunt compensation, while at the same time minimizing objective functionalities such as operating cost, active power losses, and a total severity index. The main aim is to strengthen social welfare (or to minimize the generation cost if loads are inelastic). To optimize the overall welfare benefits, the central dealers optimally ship the generators to a central pool-based sector, following organizational and safety criteria.

The problem is stated mathematically as

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

Objective Function -2 (OF-2): f_2 = Weighted multi function

Objective Function -3 (OF-3): f_3 = Weighted multi function

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 $w_1 + w_2 = 1$

F_1=S.W= Social Welfare

$$= -(Cd * Pd \_ Cs * Ps)$$

$$= \left(\sum_{i=1}^{N_G} C_{Gi}(P_G) - \sum_{i=1}^{N_D} B_{Di}(P_D)\right) \tag{13}$$

F_2 =Active power loss=

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

F_3 = Composit Logic Criteria (CLC) (15)

6. COMPREHENSIVE COMPUTER PROCEDURE TO SOLVE THE PROBLEM

The implementation steps can be described as follows in the proposed IPM-EPSO algorithm;

Step 1: Input the load flow analysis system data

Step 2: Run the power flow under the chosen network contingency

Step3: Evaluate the severity of a composite logic criteria-based approach to network contingency.

Step 4: Replay steps 2 and 3 for all lines of transformation

Step 5: Select the most severe contingencies of the network based on a fugitive logic composite severity index criteria.

Step 6a: Choose an SSSC and its system location.

Step 6b: Generate Gen =0; set IPM-EPSO simulation parameters and randomly initialize and store k individuals on the archive within their respective boundaries.

Step 7: Run the power flow under the selected network contingency for each individual in the archive to identify load bus voltages, angles, load bus voltage stability indices, generator reactive output, and line power flow calculations.

Step 8: Assess the functions of penalty

Step 9: Evaluate for each individual the objective fitness values and the respective fitness values.

Step 10: Find and store the best x_{global} and x_{local}.

Step 11: Enhance the Gen = Gen+1 generation counter.

Step 12: To generate new k individuals, apply IPM EPSO to operators

Step 13: Run power flow

Step 14: Assess the penalty functions

Step 15: Assess the fitness values of each new objective function value.

Step 16: Apply and update the IPM-EPSO Selection Operator.

Step 17: Update and save the best x_{global} & x_{local}.

Stage 18: Repeat steps 7-17 if one of the stop criteria is not fulfilled. The other way around is to stop 19

Stage 19: Printing results

7. SIMULATION RESULTS

This section provides details of the study performed on the safety enhancement of the IEEE-30 bus test system. In the IEEE 30-bus system, there are 41 branches, six generator buses, and 24 load buses. There are tap-changing transformers for four branches 6-9, 6-10, 4-12, and 27-28. There are 10, 12, 15, 17, 20, 21, 23, 24, and 29 buses with a reactive source system. The IPM-EPSO parameters used for the simulation are summarized in Table 4

Table 4: *Optimal Parameter Settings For IPM-EPSO*

Parameter	IPM-EPSO
Population size	20
Number of iterations	150
Cognitive constant, c1	2
Social constant, c2	2
Inertia weight, W	0.3-0.95

To reduce the overload of a selected severe network contingency through a solution to optimized power flow, the proposed composite logic criteria and IPM-EPSO algorithms were used. It can be seen from the Table 5 that the IP-EPSO algorithm gives less cost of generation compared with the cost of generation obtained with other methods.

Table 5 Comparison Of Fuel Costs

Method	Fuel Cost ($/hr)
EP	802.9070
TS	802.5020
OPFPSO	800.4100
MDE-OPF	802.3760
Genetic Algorithm	803.05
IPM-EPSO (proposed)	800.966

The proposed IPM-EPSO hybrid algorithm has been applied under the most severe network contingency to test the ability to solve optimal power flow problems to reduce overloads. For minimization using the proposed IPM-EPSO algorithm, three objective functions are considered. At the end of the entire generations, the algorithm was operated for a maximum of 150 generations with an overall population size of 20.

In this case, two different subcases have been analyzed. In the first sub-case, the proposed OPF without considering FACTS devices is applied on the test system to determine optimal settings of control variables under the selected single contingency. In the second sub-case, the proposed IPM-EPSO based algorithm with FACTS device (SSSC) is applied to the test system under the selected contingency.

To simulate a competitive market structure, it has been considered the generators as GENCOS and the loads as DISCOS/ESCOS. In all cases, it is assumed that they are individual entities that are operated separately. One Static Synchronous Series Compensator (SSSC) unit has been placed in line 9-10, that has turned out to be the most effective location to alleviate congestion. The specified real and reactive power flow in line 9-10 is continuously varied between the maximum and minimum limits of the real and reactive power flow of the line. SSSC real and reactive power specified values are taken as control variables of the SSSC. The limits of SSSC real and reactive power were taken as P_{min}=0.0, P_{max}=0.45, Q_{min} =0.0, and Q_{max}=0.1 p.u. The algorithm has been run for up to 150 generations and has a population of 20 and has been stopped at the end of the generations.

The convergence characteristics of different objective functions with and without SSSC under the top 1 contingency 2-5 are shown in Figures 4-8 From Figures 4-8, it can be observed that the objective functions 1, 2 & 3 converged to their minimum value within 50 iterations.

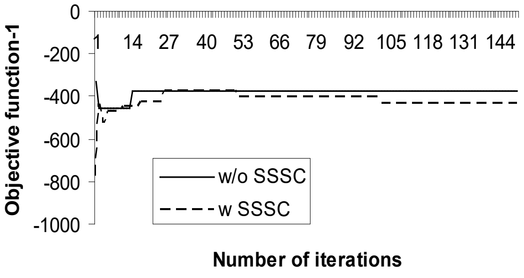

Figure 4 Convergence Diagram Of Objective Function-1

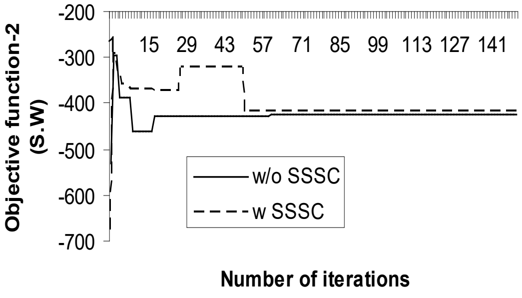

Figure 5 Convergence Diagram Of Objective Function-2 (S.W)

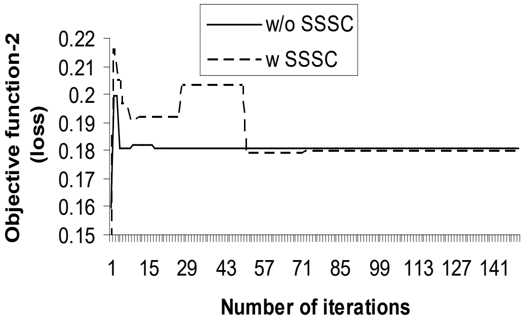

Figure 6 Convergence Diagram Of Objective Function-2 (Loss)

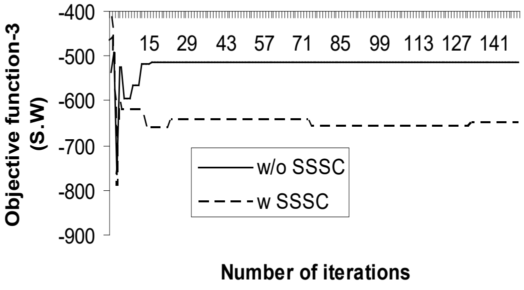

Figure 7 Convergence Diagram Of Objective Function-3 (S.W)

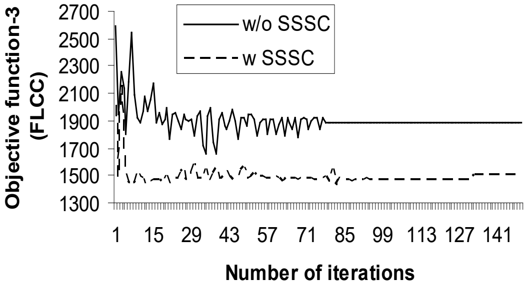

Figure 8 Convergence Diagram Of Objective Function-3 (Loss)

Table 5 presents the optimal settings of the control variables obtained from the optimal power flow solution with and without SSSC under the top contingency. From Table 4, it can be observed that all control variables are maintained within their limits during the minimization of the specified objective function. The optimal real power load levels obtained from the OPF solution are given in Table 6. From Table 4, it is also observed that the proposed IPM-EPSO based hybrid algorithm with SSSC effectively works to maximize social welfare while improving network security.

Table 5 Optimal Settings Of Control Variables

Control variable (p.u)	O.F					
	O.F - 1		O.F- 2		O.F- 3	
	Without SSSC	With SSSC	Without SSSC	With SSSC	Without SSSC	With SSSC
PG-1	1.3198	1.5265	1.4750	1.4389	1.2736	1.1986
PG-2	0.6595	0.5152	0.5719	0.6508	0.6873	0.6282
PG-3	0.2386	0.2744	0.2311	0.1824	0.2060	0.2346
PG-4	0.1873	0.2086	0.2365	0.2180	0.1744	0.2402
PG-5	0.4916	0.2486	0.3311	0.2439	0.3617	0.4292
PG-6	0.2344	0.3003	0.2806	0.2929	0.2830	0.2559
VG-1	1.0611	1.0720	1.0519	1.0081	1.0139	1.0204
VG-2	0.9760	1.0049	0.9894	1.0278	1.0581	1.0124
VG-3	0.9928	1.0178	1.0007	1.0504	1.0359	0.9973
VG-4	0.9876	1.0082	0.9991	1.0094	0.9901	1.0436
VG-5	1.0505	1.0411	1.0425	1.0413	1.0059	1.0247
VG-6	1.0353	1.0045	1.0123	1.0490	1.0638	1.0151
Tap1	0.9700	0.9700	0.9700	0.9500	1.0300	1.0100
Tap2	0.9600	1.0600	1.0100	1.0300	1.0500	1.1000
Tap3	1.0300	1.0200	0.9300	1.0200	0.9800	0.9900
Tap4	0.9600	1.0400	1.0400	1.0000	1.0300	1.0400
Qsh-10	0.1200	0.0600	0.1200	0.0600	0.0600	0.0600
Qsh-12	0.1200	0.0600	0	0	0	0.0600
Qsh-15	0	0.0600	0.1800	0.1200	0.1200	0.1800
Qsh-17	0.0600	0.0600	0.1200	0	0.1200	0.0600
Qsh-20	0.1200	0	0	0.1800	0.0600	0.0600
Qsh-21	0.1200	0.0600	0.1200	0.1200	0	0
Qsh-23	0	0.0600	0.1200	0.1200	0.1200	0.1200
Qsh-24	0.0600	0.1800	0.0600	0.0600	0	0.0600
Qsh29	0.1800	0.1200	0	0.0600	0.1800	0
P-Loss (p.u)	0.2006	0.1789	0.1808	0.1793	0.1455	0.1139
S.W.($/hr)($f_1$)	-376.1382	-430.6815	-425.5297	-416.3540	-515.5875	-650.3494
CLC	1903.9	1653.8	1776.6	2667.9	1891.3	1504.6
VSe	-	0.0333	-	0.0278	-	0.0351
θ_{Se}	-	-120.220	-	-104.520	-	-103.730

From Tables 5 & 6, it is a proven fact that the proposed IPM-PSO algorithm gives a better solution not only for multiple objective functions but also for weighted sum multi-objective functions. It is also be noted that placement of SSSC at line 9-10 is an effective measure to improve the system security in a deregulated environment.

Table 7 provides details of the number of lines/buses under different severity categories. The number of buses falling under the most severe category has been eliminated during minimization of objective function 3 which involves CLC based severity index in the weighted sum multi-objective function. Hence, consideration of weighted sum multi-objective function involving CLC based severity index is an effective alternative to maximize social welfare, without compromising on the system security.

Table 6 Optimal Real Power Load Levels

Load Bus Power	Limits		O.F					
			O.F -1		O.F- 2		O.F- 3	
	Min	Max	Without SSSC	With SSSC	Without SSSC	With SSSC	Without SSSC	With SSSC
P_{L-1}	0	0	0	0	0	0	0	0
P_{L-2}	0.1845	0.2495	0.2191	0.2236	0.2294	0.1959	0.2088	0.2321
P_{L-3}	0.2550	0.3450	0.2922	0.3048	0.3156	0.2906	0.2873	0.3081
P_{L-4}	0	0	0	0	0	0	0	0
P_{L-5}	0.8007	1.0833	0.9584	0.9709	0.9593	0.9931	0.9465	0.9228
P_{L-6}	0	0	0	0	0	0	0	0
P_{L-7}	0.1938	0.2622	0.2455	0.2401	0.2436	0.2090	0.2277	0.2481
P_{L-8}	0.0204	0.0276	0.0247	0.0238	0.0249	0.0248	0.0227	0.0241
P_{L-9}	0	0	0	0	0	0	0	0
P_{L-10}	0.0493	0.0667	0.0640	0.0580	0.0598	0.0609	0.0594	0.0634
P_{L-11}	0.0646	0.0874	0.0751	0.0830	0.0718	0.0815	0.0748	0.0817
P_{L-12}	0.0952	0.1288	0.1250	0.1189	0.1217	0.1107	0.1153	0.1081
P_{L-13}	0	0	0	0	0	0	0	0
P_{L-14}	0.0527	0.0713	0.0571	0.0615	0.0677	0.0587	0.0623	0.0710
P_{L-15}	0.0697	0.0943	0.0826	0.0811	0.0886	0.0744	0.0794	0.0835
P_{L-16}	0.0298	0.0402	0.0337	0.0351	0.0347	0.0345	0.0356	0.0319
P_{L-17}	0.0765	0.1035	0.0904	0.0882	0.0932	0.0854	0.0974	0.0977
P_{L-18}	0.0272	0.0368	0.0341	0.0317	0.0321	0.0290	0.0328	0.0325
P_{L-19}	0.0808	0.1092	0.0955	0.0990	0.0879	0.0983	0.0936	0.0938
P_{L-20}	0.0187	0.0253	0.0196	0.0217	0.0224	0.0225	0.0230	0.0202
P_{L-21}	0.1487	0.2013	0.1796	0.1716	0.1782	0.1872	0.1590	0.1739
P_{L-22}	0	0	0	0	0	0	0	0
P_{L-23}	0.0272	0.0368	0.0311	0.0310	0.0297	0.0338	0.0317	0.0306
P_{L-24}	0.0739	0.1000	0.0884	0.0820	0.0771	0.0860	0.0909	0.0835
P_{L-25}	0	0	0	0	0	0	0	0
P_{L-26}	0.0298	0.0402	0.0354	0.0384	0.0361	0.0331	0.0342	0.0373
P_{L-27}	0	0	0	0	0	0	0	0
P_{L-28}	0	0	0	0	0	0	0	0
P_{L-29}	0.0204	0.0276	0.0240	0.0249	0.0231	0.0246	0.0228	0.0228
P_{L-30}	0.0901	0.1219	0.1078	0.1053	0.1085	0.1135	0.1076	0.1057
TTL (p.u)			2.8833	2.8946	2.9054	2.8475	2.8128	2.8728

Table 7 Buses under different severity categories

O.F		Line Loadings				Bus Voltage Profiles			Bus Voltage Stability Indices				
		LS	US	SA	HS	US	SA	HS	VLS	LS	US	SA	HS
Before Optimization		28	8	2	2	0	8	16	24	0	0	0	0
O.F 1	Without SSSC	28	8	1	3	0	20	4	24	0	0	0	0
	With SSSC	27	9	2	2	0	24	0	24	0	0	0	0
O.F 2	Without SSSC	27	9	2	2	0	21	3	24	0	0	0	0
	With SSSC	26	10	1	3	0	5	19	24	0	0	0	0
O.F 3	Without SSSC	27	10	3	0	0	17	7	24	0	0	0	0
	With SSSC	28	10	2	0	0	24	0	24	0	0	0	0

Figure 9 to 11 represents the line loadings for three objective functions under the contingency of line 2-5 with and without SSSC. The efficiency of the proposed IPM-EPSO hybrid algorithm and the superiority of SSSC in maintaining good load bus voltages profiles and voltage stability indices within limits can be observed from the respective Figures 12-17.

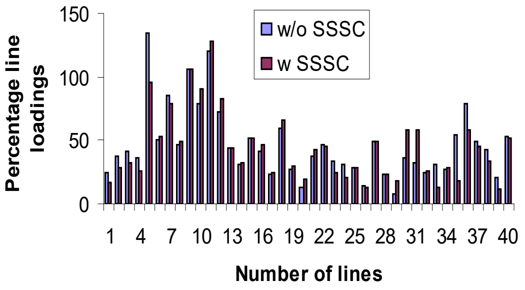

Figure 9 Line Loadings (Objective Function-1)

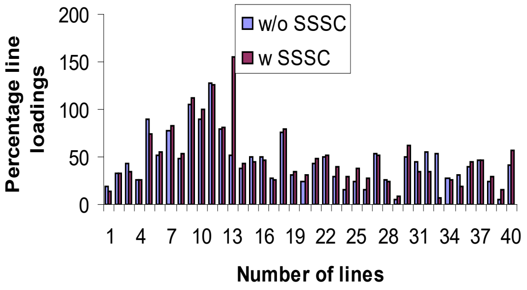

Figure 10 Line Loadings (Objective Function-2)

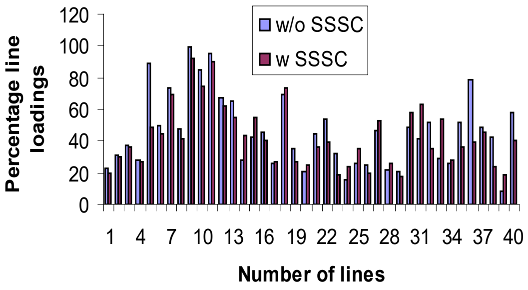

Figure 11 Line Loadings (Objective Function-3)

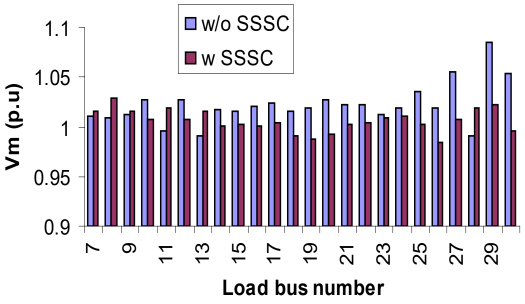

Figure 12 Load Bus Voltage Profiles (Objective Function-1)

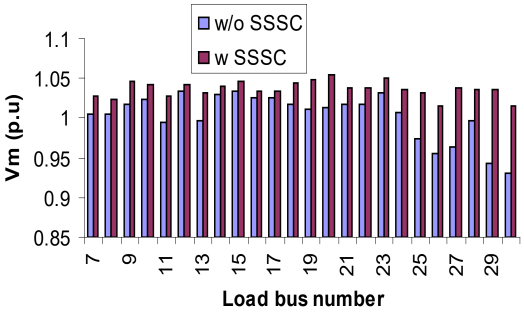

Figure 13 Load Bus Voltage Profiles (Objective Function-2)

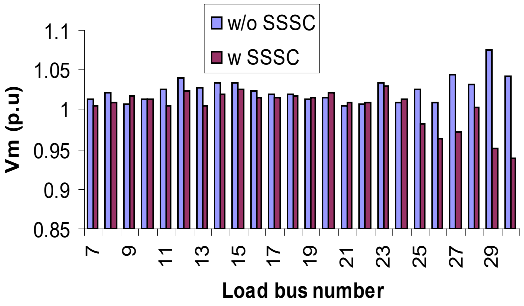

Figure 14 Load Bus Voltage Profiles (Objective Function-3)

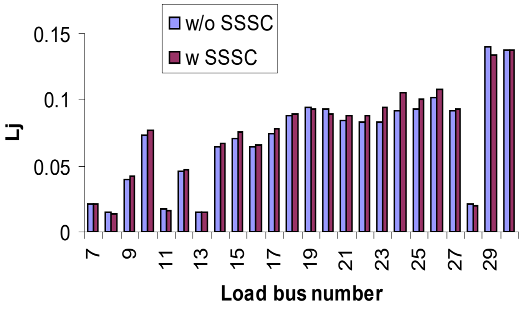

Figure 15 Voltage Stability Indices (Objective Function-1)

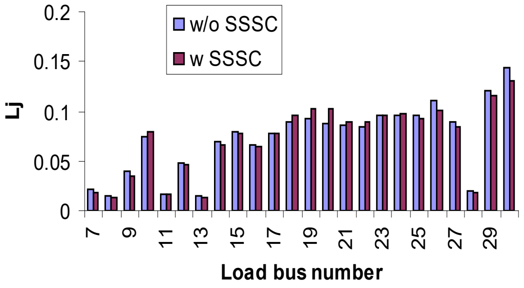

Figure 16 Voltage Stability Indices (Objective Function-2)

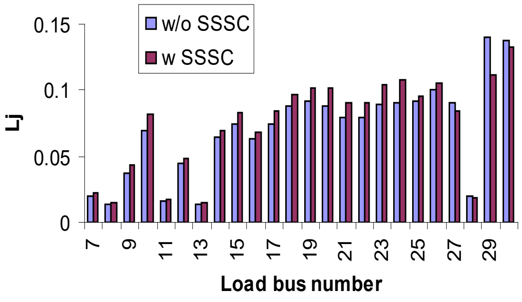

Figure 17 Voltage Stability Indices (Objective Function-3

8. CONCLUSION

This paper proposed an approach based on the composite logical criteria for the power system network. In addition to real power changes and bus voltages, the proposed method uses the voltage stability indexes for load buses as post-contingent quantities for estimating the composite logic criteria. These quantities were expressed in a fuzzy set notation. The fuzzy rules are then used to find the entire severity index of the system. This article proposed a new technique in the operation of deregulating power systems to maintain system security, with an emphasis on voltage stability. To solve the optimal power flow problem with a weighted sum multi-objective function, an IPM-EPSO method is being applied to maximize social benefits and network security. Due to a reprogram of generator outputs, line overloads have been alleviated, losses reduced and the system safety improved. On the modified IEEE 30- bus system, the effectiveness of the approach proposed has been demonstrated. Other heuristic methods can be used to solve similar problems.

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