Electrical and Electronics Engineering: An International Journal (ELELIJ) Vol.5, No.4, November 2016

RELIABILITY EVALUATION WITH EFFECTS ON SYSTEM PARAMETERS INCORPORATING FACTS DEVICES

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ABSTRACT

A modern power system is highly integrated and is usually very large and complex. The power systems which are having shortage of reactive power due to fault or heavy load on it, experiences a voltage collapse. So reserve source of reactive power is required for the stable operation of power system FACTs devices can be used for reactive power management and it is having significant impacts on reliability evaluation of composite power system. Under such circumstances, load shedding is usually last option used to avoid voltage collapse condition. This paper suggests a model to evaluate reliability indices incorporating SVC and TCSC with fuzzy penalty using GA based priority load curtailment. A comparative study is done for the results obtained using SVC and TCSC with and without fuzzy penalty. The proposed algorithms are tested on WSCC RBTS and 24 Bus – IEEE reliability test system.

KEYWORDS:

SVC, TCSC, Load curtailment, Reliability, GA, Fuzzy Penalty.

1. INTRODUCTION

In the coming year modern power system facing many challenges due to complex structure and its operation. The power consumption is expected to be double in developing and transition countries where as in developed countries it is increase by 35-40%. Incidences occurred over several year shows that voltage stability and power system reliability is a major concern. Voltage stability is the ability of system to maintain the voltage magnitude when the power transferred to load increases [1-3].

There is challenge to meet the demand of customers uninterrupted reliable power supply with quality. One way is that to use the existing equipments up to their maximum capacity. FACTS devices increase the thermal capacity of transmission line, also increases the reliability of the system.

The power systems which are having shortage of reactive power due to fault or heavy load on it, experiences a voltage collapse [4]. Today mostly power systems are being operate close to the transmission system thermal and stability limit. There are certain constraints which limit the operation of transmission system such as cost, limit the expansion of transmission

DOI : 10.14810/elelij.2016.5402

networks. Maximize utilization of the existing transmission system may sometime leads to insecure and unstable operation of power system.

In actual power system load buses are more or less sensitive to voltage stability. So the suitable placement of FACTS devices enhances the voltage stability to great extent and hence improves the reliability of the power system. Reliability study is performed in two domains as adequacy and security. System adequacy is related to generation transmission and distribution of existing system to satisfy customer load demand. System security is related to disturbances arising within system. The use of FACTS devices in power system has significant impact on power system reliability performance. One of the applications of FACTS device is to use as a interconnecting links between major system or from remote power station to major system. The use of FACTS devices in transmission system can change the basic load flow pattern and used to improve the reliability of power system. The purpose of evaluation of the reliability of a composite power system is to determine the ability of the system to supply energy to the bulk supply points with maintaining network stability during faults, switching, and other disturbances.

In [5-8], some security-constrained adequacy evaluation methodologies are presented. OPF problems are formulated to minimize the load curtailment using remedial actions. Linear programming algorithms for remedial actions that control active power [6-9] and reactive power [10] are derived. Some techniques, including the simplex method and the interior point method [11], are applied to solve the formulated optimal power flow problem.

In analytical techniques, a mathematical model of system is developed and using these, model reliability indices are evaluated. The most widely used analytical method is the contingency enumeration approach [12]. In analytical technique, system contingencies, such as line failures, unit outages, or both, are derived using certain criterion such as up to certain level. System contingencies represent system failures, identified to test system contingencies against some predetermined criteria. Impact of such contingencies on the system, such as line loading and bus voltages, is obtained by solving power flows. Based on the results of effects analysis, system reliability indices can be calculated [13-14].

Voltage stability refers to the ability of a power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition [15].Fault on transmission line or insufficient generation can create power mismatch between generation and load. Shortage of generation to satisfy load, effective load curtailment acton is required to maintain the supply–demand balance. Load shedding is a process of dcutting alow priority load without disturbing the stability of the remaining network [16]. Accurate load shedding avoid violate instability as well as loss of revenue to power utility. In [17] the buses, anticipatory action of load shedding by selecting load buses for optimum load shedding at selected buses based on the sensitivity of minimum eigenvalue of load flow Jacobian for voltage stability with respect to load shed. Bijwe et al.[18]. developed an anticipatory load shedding technique using LP formulation for loadability enhancement. Luan et al. [19] developed optimal load shedding algorithm using genetic algorithm for distribution network.

Generally, solution of optimal power flow is obtained by adjusting control variables in a specific by satisfying the specified equality and inequality constraints. Conventionally, the voltages of buses with (minimum and maximum magnitude limits) are considered as the control variables, which are varied in a certain direction to obtain the state variables, which satisfies all constraints with optimal objective function.

Series compensation with Thyristor Control (TCSC) enables rapid dynamic modulation of the inserted reactance. At interconnection points between transmission grids, this modulation will provide strong damping torque on inter-area electromechanical oscillations. As a consequence, a TCSC makes it possible to interconnect grids having generating capacity in many thousands of megawatts. TCSC with fixed series compensation are generally used to improve transient stability. Series compensation of power transmission circuits enables several useful benefits:

Increases active power flow of transmission line without violating angular or voltage stability;

An increase of angular and voltage stability without derating power transmission capacity;

A decrease of transmission losses in many cases.

Application GAOPF with voltages as control vector leads to a slow convergence problem, as GA is random population based search algorithm. In this case, the GA utilizes large generations and without guaranteed convergence. Considering, these disadvantages, this study suggests, Simple GA based AC OPF with GA based priority load curtailment methods are used to calculate the reliability indices with effects on voltage stability, real and reactive power flow.

2. STATIC VAR COMPENSATOR MODELLING

A static VAR compensator (SVC) is device used to improve the voltage profiles in the transient state and therefore, in improving the performances and quality of the electric services. A SVC is one of FACTS controllers, which can control one or more variables in a power system.

A Static VAr Compensator can generate and absorb variable reactive power continuously using discrete components of fixed and switched shunt capacitors or reactors. SVC is a source of continuous variable reactive power supply, the SVC bus voltage may be control smoothaly and also active power transfers or system loading conditions. This reduces the active power loss of netwok.

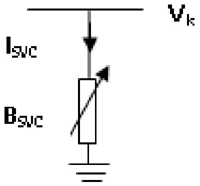

Figure 1- Model of SVC

From figure 1 the current drawn by SVC is given by equation as

$$I_{SVC} = jB_{SVC} V_K \quad (1)$$

Reactive power drawn by SVC that is the same as injected power to bus k is given as

$$Q_{SCVC} = Q_K = -B_{SVC} V_K^2$$

2.1 Reliability Modelling of SVC

A TSC-TCR type SVC consists of a certain number of TSCs and TCRs. We are mainly concern with the failures of these components, which are in parallel. To set up the reliability model of the SVC, we make the following assumptions:

After a TSC or TCR fails, it will be isolated by a bypass breaker. Therefore other normal components can still work. If all the TSCs and TCRs of the SVC fail, the SVC will be simply disconnected by a bypass breaker from the transmission line with which the SVC is in parallel. The state-space model of the SVC is shown in the figure 2.

From figure 2, state **1** where both the TSC and TCR are in up condition i.e both are working, the SVC can either absorb or generate reactive power. TCR is down in state 2 and isolated by a bypass breaker from the rest of the SVC. However, the SVC still can provide VAR, which controls the available TSC. State 3 is similar to state 2. The SVC now can only absorb reactive power because only the TCR is available. The SVC has no effect in state 4 where both the TSC and TCR are down.

From figure 2 the probability of each state is

$$\boldsymbol{P_1} = \frac{\boldsymbol{\mu_1\mu_2}}{(\boldsymbol{\lambda_1}+\boldsymbol{\mu_1})(\boldsymbol{\lambda_2}+\boldsymbol{\mu_2})}$$

$$\boldsymbol{P_2} = \frac{\boldsymbol{\mu_1\lambda_2}}{(\boldsymbol{\lambda_1}+\boldsymbol{\mu_1})(\boldsymbol{\lambda_2}+\boldsymbol{\mu_2})}$$

$$\boldsymbol{P_3} = \frac{\boldsymbol{\lambda_1\mu_2}}{(\boldsymbol{\lambda_1}+\boldsymbol{\mu_1})(\boldsymbol{\lambda_2}+\boldsymbol{\mu_2})}$$

$$\boldsymbol{P_4} = \frac{\boldsymbol{\mu_1\mu_2}}{(\boldsymbol{\lambda_1}+\boldsymbol{\mu_1})(\boldsymbol{\lambda_2}+\boldsymbol{\mu_2})}$$

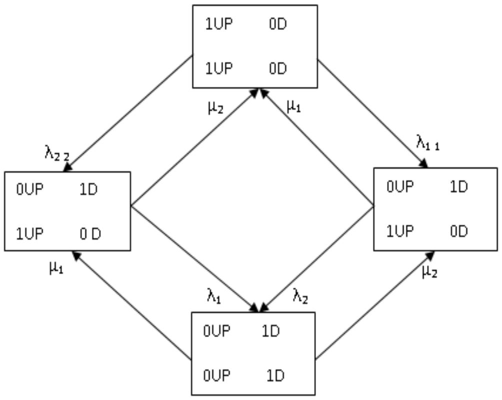

Figure 2: State space diagram of SVC

Where

λ_1 and λ_2 are failure rate of TSC and TCR respectively
μ_1 and μ_2 are the repair rate of TSC and TCR respectively.
$P_{UP} = P_1 + P_2 + P_3$
$P_{DOWN} = P_4$

3. TCSC MODELLING

Series compensation with Thyristor Control (TCSC) enables rapid insertion of reactance. At interconnection points between transmission grids, this modulation will provide strong damping torque on inter-area electromechanical oscillations. As a consequence, a TCSC makes it possible to interconnect grids having generating capacity in many thousands of megawatts.

The reliability analysis for the combination of TCSC can be determined by using either Series-Parallel representation or State Space representation. However, network reduction techniques cannot be applied for all the systems where the availability of the system should be predicted accurately, state space representation will be used in place of network reduction techniques.

3.1 Reliability Model of TCSC

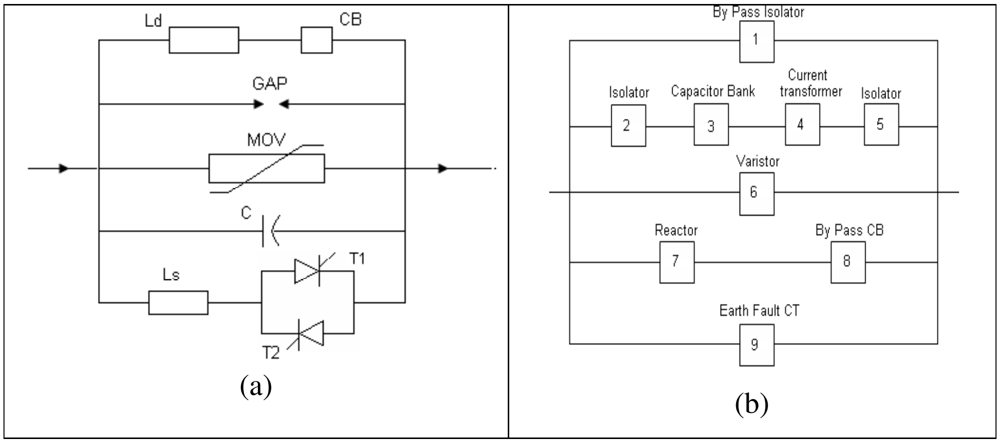

Figure 3 (a): Block Diagram of Practical TCSC showing various components
Figure 3(b): RLD for combination of TCSC using Series – Parallel System

The Reliability Logic Diagram (RLD) of Thyristor Controlled Series Compensator system is shown in figure 4. Each rectangle block in the figure 3(b) represents a particular component. Here each component has its own reliability which is independent of the time. Considering these reliabilities, in combination of simple series and parallel system, the overall reliability and unreliability of the system are determined as follows:

Here the rectangular blocks from 1 to 16 represents the transition state out of 18 states of TCSC. The upper transition represents the states of TCSC module 1 and lower transitions represent states of TCSC modules 2. Here, only 16 states are considered and the remaining states does not with stand the rated capacity of the transmission line.

Each and every state is connected to bypass module, because, at any state the system can be failed due to any faults or improper firing of thyristors or failure of capacitors in series compensator. Each state represented sequentially with proper number so that, each state follows the previous sates. A bypass block is also considered because, to reduce the capacitor voltage which is due to fault currents.

The capacities associated with state 2 to 16 are proportional to the number of the available modules. The post pone or spare state 17 is a transition state between states1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16 and state 18

$$P_1(1-2\lambda)+P_2\,\mu+P_5\,\mu+P_{18}\,\mu=P_1 \tag{1}$$

$$P_1\lambda+P_2\big(1-(\mu+3\lambda)\big)+P_3\mu+P_6\mu+P_{18}\,\mu=P_2 \tag{2}$$

$$P_2\lambda+P_3\big(1-(\mu+3\lambda)\big)+P_4\mu+P_7\mu+P_{18}\,\mu=P_3 \tag{3}$$

$$P_3\lambda+P_4\big(1-(\mu+\lambda)\big)+P_8\mu+P_{11}\mu=P_4 \tag{4}$$

$$P_1\lambda+P_5\big(1-(\mu+3\lambda)\big)+P_6\mu+P_9\mu+P_{18}\,\mu=P_5 \tag{5}$$

$$P_2\lambda+P_5\lambda+P_6\big(1-(2\mu+4\lambda)\big)+P_7\mu+P_{10}\,\mu+P_{18}\mu=P_6 \tag{6}$$

$$P_3\lambda+P_6\lambda+P_7\big(1-(2\mu+4\lambda)\big)+P_8\mu+P_{11}\mu+P_{18}\mu=P_7 \tag{7}$$

$$P_4\lambda+P_7\lambda+P_8\big(1-(2\mu+\lambda)\big)+P_{12}\mu+P_{18}\mu=P_8 \tag{8}$$

$$P_5\lambda+P_9\big(1-(\mu+3\lambda)\big)+P_{10}\mu+P_{13}\mu+P_{18}\mu=P_9 \tag{9}$$

$$P_6\lambda+P_9\lambda+P_{10}\big(1-(2\mu+4\lambda)\big)+P_{11}\mu+P_{14}\mu+P_{18}\mu=P_{10} \tag{10}$$

$$P_7\lambda+P_{10}\lambda+P_{11}\big(1-(2\mu+4\lambda)\big)+P_{12}\mu+P_{15}\mu+P_{18}\mu=P_{11} \tag{11}$$

$$P_8\lambda+P_{11}\lambda+P_{12}\big(1-(2\mu+\lambda)\big)+P_{16}\mu+P_{18}\mu=P_{12} \tag{12}$$

$$P_9\lambda+P_{13}\big(1-(\mu+\lambda)\big)+P_{14}\mu+P_{18}\mu=P_{13} \tag{13}$$

$$P_{10}\lambda+P_{13}\lambda+P_{14}\big(1-(2\mu+\lambda)\big)+P_{15}\mu+P_{18}\mu=P_{14} \tag{14}$$

$$P_{11}\lambda+P_{14}\lambda+P_{15}\big(1-(2\mu+\lambda)\big)+P_{16}\mu+P_{18}\mu=P_{15} \tag{15}$$

$$P_{12}\lambda+P_{15}\lambda+P_{16}(1-2\mu)+P_{18}\mu=P_{16} \tag{16}$$

$$P_2\lambda+P_3\lambda+P_5\lambda+P_6\lambda+P_7\lambda+P_9\lambda+P_{10}\lambda+P_{11}\lambda+P_{17}(1-2\lambda)=P_{17} \tag{17}$$

$$P_{17}\lambda+P_{18}(1-16\mu)=P_{18} \tag{18}$$

Since all the above Eqns. (1) to (18) are independent to each other, we consider only 17 equations out of the above 18 equations and 18th equation is taken as

$$P_1+P_2+P_3+P_4+P_5+P_6+P_7+P_8+P_9+P_{10}+P_{11}+P_{12}+P_{13}+P_{14}+P_{15}+P_{16}+P_{17}+P_{18}=1 \tag{19}$$

Consider the data:

Failure Rate (λ) = 0.7 f/yr
Repair Rate (μ) = 150 hrs of each component,

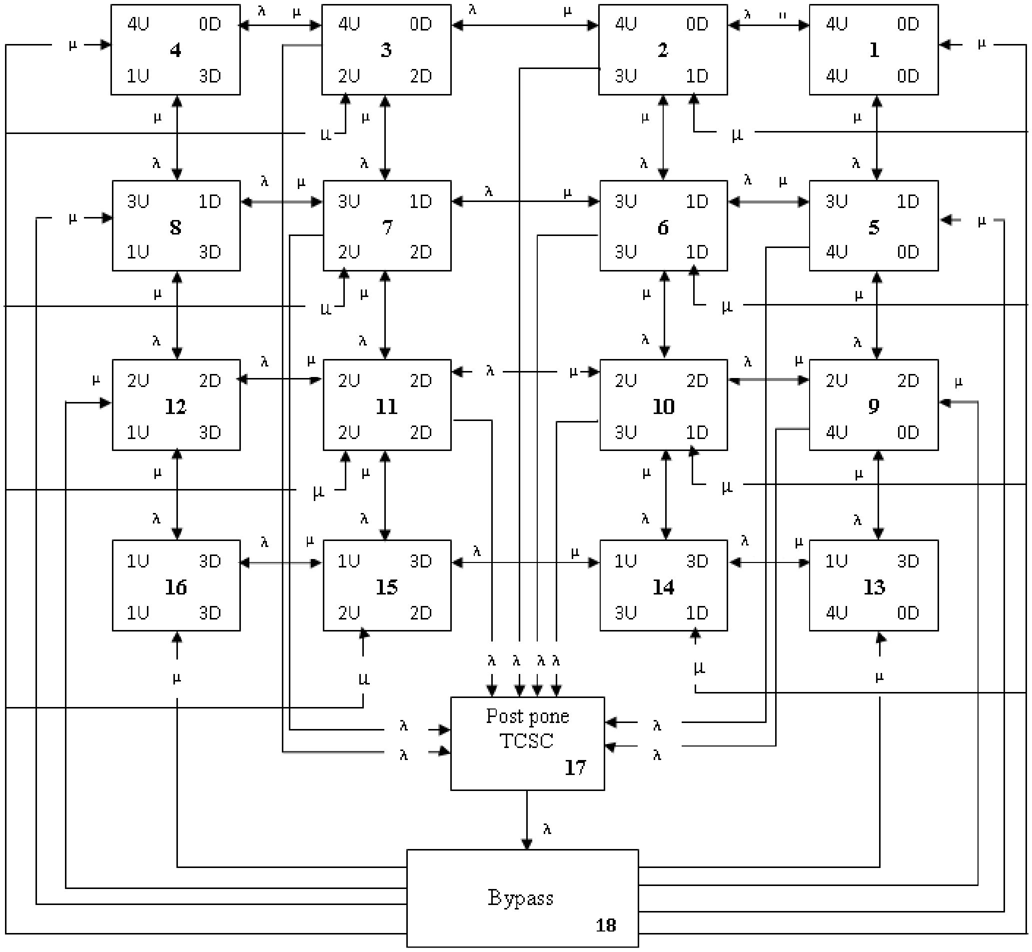

Figure 4: State space diagram of two modules TCSC.

then Individual Limiting State Probabilities are:

$P_1 = 0.9827$ $P_2 = 0.0065$ $P_3 = 0.00025$ $P_4 = 1.2$ e-4
$P_5 = 2.3$ e-5 $P_6 = 11.2$ e-6 $P_7 = 23.2$ e-6 $P_8 = 13.2$ e-7
$P_9 = 43.8$ e-8 $P_{10} = 47.8$ e-8 $P_{11} = 12.8$ e-9 $P_{12} =53.2$ e-10
$P_{13} = 12.6$ e-11 $P_{14} = 11.8$ e-12 $P_{15} = 14.7$ e-13 $P_{16} =12.3$ e-14
$P_{17} = 0.007$ $P_{18} = 27.3$ e-6

Therefore, the sum of the limiting state probabilities is

$$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} + P_{13} + P_{14} + P_{15} + P_{16} + P_{17} + P_{18} = 1$$

Availability of the system (P_{UP}) = P_1+P_{17} = 0.9827 + 0.007 = 0.9897

Unavailability (P_{DOWN}) = 1- 0.9882 = 0.0103

3.2 Reliability Model of Generator and Transmission Line

In the following figure component 1 is considered as either generator or transmission line. State 1 is a up state where component is in working condition and state 2 represent the down state.

Figure 5: State space model of generator and transmission line

λ and μ are the failure and repair rate of component respectively.

From figure 3 the probability of each state is

$$P_1 = P_{UP} = \frac{\mu}{(\lambda+\mu)} \tag{19}$$

$$P_2 = P_{DOWN} = \frac{\lambda}{(\lambda+\mu)} \tag{20}$$

4. PROPOSED ALGORITHMS

In this study Simple genetic based OPF with fixed penalty (SGA_PV) and Simple genetic based OPF with fuzzy penalty (SGA_PV_FP) is proposed to derive the reliability indices with voltage stability, real and reactive power flow with optimal placement of SVC and TCSC using priority based load curtailment.

4.1 Load Curtailment Problem Statement

Let n_{LB} be the no. of load buses.

Let λ_1, λ_2, …………, $\lambda\, n_{LB}$ load curtailment variables.
The load curtailment objective function will be

$$\min f_\lambda = \sqrt{\lambda_1^2 + \lambda_2^2} + \cdots + \lambda_{nLB}^2 \tag{21}$$

Subject to the constraints

i) Inequality Constraints

$$P_{gi}^{min} < P_g < P_{gi}^{max} \qquad i = 1,2,\dots\dots\dots,n_{gb}$$

$$Q_{gi}^{min} < Q_g < Q_{gi}^{max} \qquad i = 1,2,\dots\dots\dots,n_{gb} + n_{vcb}$$

$$|P_{TLi}| < |P_{TLi}|^{max}$$

$$E_p^{min} \leq E_p \leq E_p^{max} \qquad p = 1,2,\dots\dots\dots..,n$$

Where

$n ------$ $no.\,of\ buses$
$n_{gb} -----$ $no.\,of\ generating\ buses$
$n_{vcb} -----$ $no.\,of\ voltage\ contro\ buses$
$n_{TL} ------$ $no.\,of\ transmission\ lines$

ii) Equality constraints

$$P_{Lp}(1 - \lambda_p) = 0 \qquad p = 1, 2, \dots\dots\dots, n_{LB}$$

$$Q_{Lp}(1 - \lambda_p) = 0 \qquad p = 1, 2, \dots\dots\dots, n_{LB}$$

Where

$$P_p = \sum_{p=1}^{nb}\sum_{q=1}^{nb}\left|E_p E_q Y_{pq}\right| \cos(\delta_{pq}\, O_{pq})$$

$$Q_p = \sum_{p=1}^{nb}\sum_{q=1}^{nb}\left|E_p E_q Y_{pq}\right| \cos(\delta_{pq}\, O_{pq})$$

Algorithm 1 - Simple genetic based OPF with fixed penalty (SGA_PV)

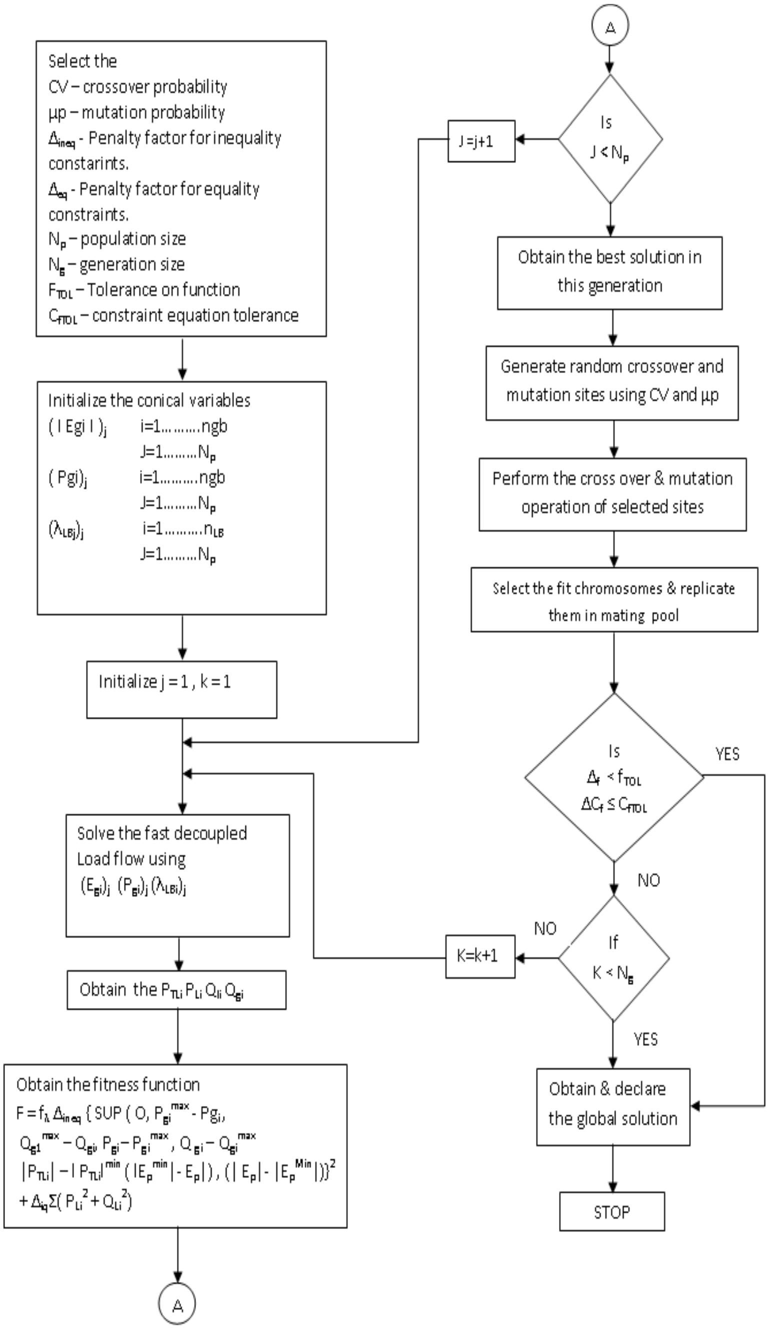

Figure 6: Flow chart of SGA based Load curtailment with fixed penalty

Algorithm 2 - Simple genetic based OPF with fuzzy penalty (SGA_PV_FP)

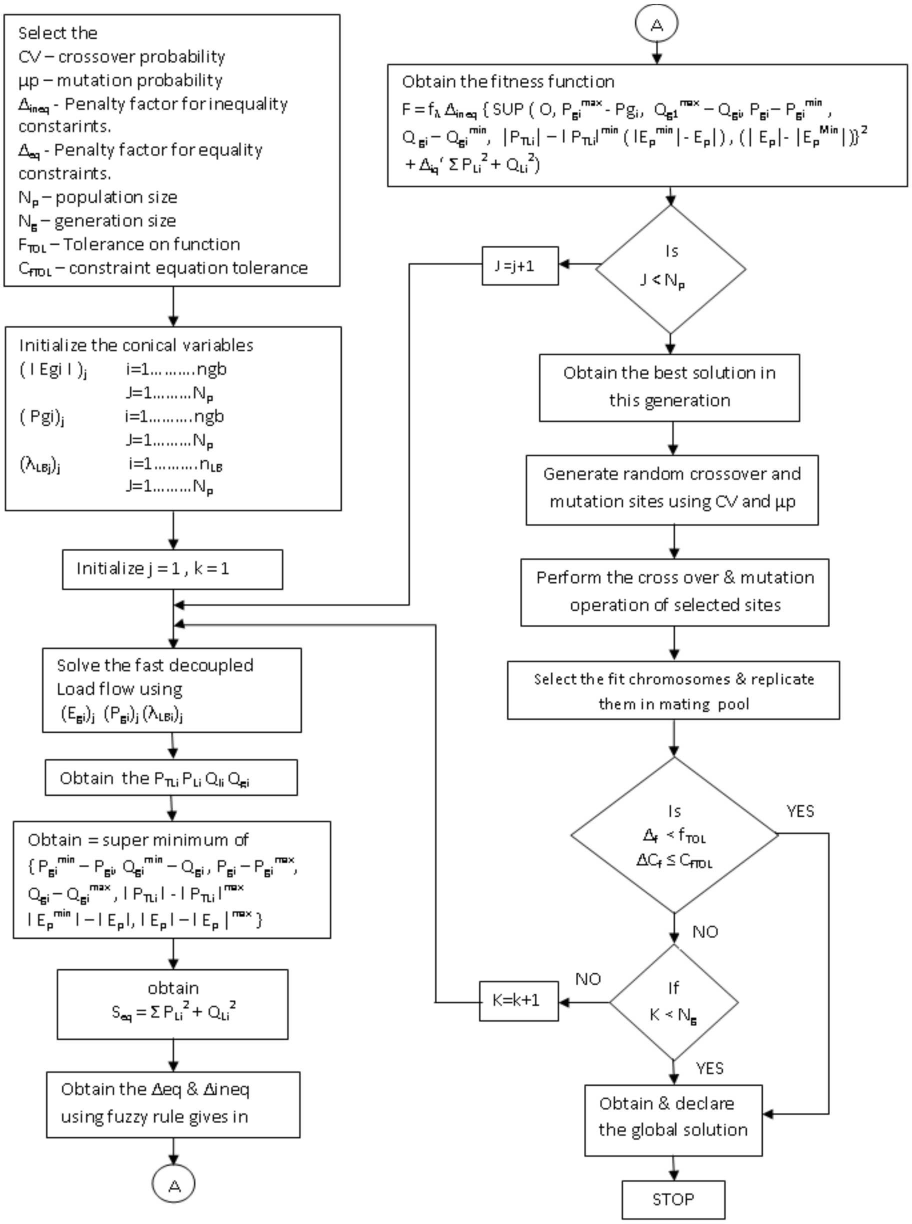

Figure 7: Flow chart of SGA based Load Curtailment with variable penalty

5. RELIABILITY INDICES

Expected Load Curtailment (ELC)

$$ELC = \sum_j L_{kj} . F_j \; MW \; /Yr$$

Expected Energy Not Supplied (EENS)

$$\boldsymbol{EENS = \sum_j L_{kj}\,.F_j.D_{Kj}\ \ MWh\,/Yr}$$

Expected Duration of Load Curtailment (EDLC)

$$\boldsymbol{EDLC\ = \sum_j F_j.D_{Kj}\ \ hours\,/Yr}$$

No. of Load Curtailment

$$\boldsymbol{NLC\ = \sum_j F_j.P_{Kj}\ \ /Yr}$$

Where,

j: an outage condition in the network,
P_j: the state probability of the outage event j,
F: frequency of occurrence of the outage event j,
P_{Kj} : probability of load curtailment at bus k,
L_{Kj}: load curtailment at bus k during outage,
D_{Kj} : duration in hours of load curtailment at bus k, during outage event j

5.1 Reliability calculation incorporating the load curtailment

The flow chart for determination of reliability indices including load curtailment is shown and explained below

1. Read the system data.
2. Generate the contingency (n).
3. Calculate the availability and unavailability of the component / devices using equation (19), (20)
4. Calculate the probability of the state jth contingency.
5. Is the probability less than 10^{-06}
Go to the step 6
Else go to the step 2
6. Update the system data.
7. Obtain Bus incidence, cut set bus admittance for modified system.
8. Choose initial state and control variable for load curtailment problem.
9. Solve the load curtailment problem using equation (21).
10. Is load flow constrained satisfied and λ is minimised.
Go to the step 11
Else go to the step 9
11. Calculate reliability indices.
12. Is all the contingencies solved
Go to step
Else go to step 2
13. Stop

6. RESULTS AND DISCUSSION

The above proposed algorithms are tested on

9 Bus WSCC,
6 Bus RBTS and
24 Bus IEEE reliability test system.

The SVC and TSCS compensation devices are used independently. The proposed state model of TSCS is used during the study.

6.1 Simulation data of WSCC system

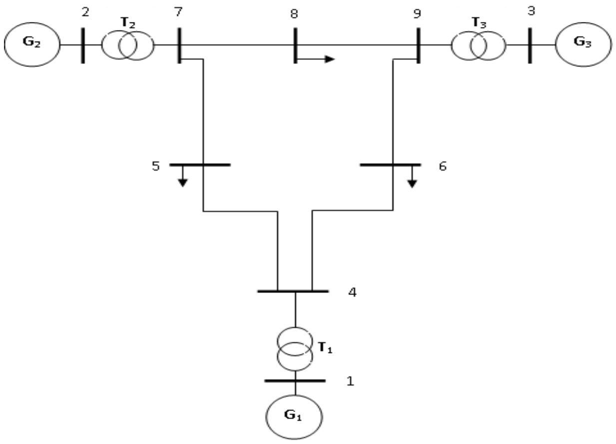

Figure 8: Single Line Diagram of WSCC 9 Bus System

The WSCC 9 bus system consist of three generators connected to Bus1, Bus2 and Bus3 respectively. Generator1 at Bus1 have maximum generating capacity of 247.5 MW. Generator 2 and 3 are having 192 MW and 128 MW generating capacity respectively and nine interconnected transmission lines.

Failure and repair rate of generators are 5 occ/yr and 195 occ/yr respectively.
Failure and repair rate of transformers are 4 occ/yr and 196 occ/yr respectively.
Failure and repair rate of transmission lines are 5 occ/yr and 193 occ/yr respectively

6.1.1 Reliability indices using proposed algorithms

Single generator contingent condition is assumed to determine the generator reliability indices of the system.

Single transmission line contingent condition is assumed to determine the transmission line reliability indices of the system.

Up to three contingency of 1e-12, 1e-10 and 1e-06 probability limits are considered during the reliability analysis of WSCC, RBTS and IEEE 24 bus system respectively.

378, 1178 and 3500 contingencies of WSCC, RBTS and IEEE system respectively are selected to represent the composite reliability indices.

Table 1: Reliability indices of WSCC system using algorithm SGA_PV and SGA_PV_FP

Type of reliability Indices	**Types of Reliability**	**SGA_PV**			**SGA_PV_FP**		
		w/o comp	**SVC Bus 4**	**TCSC Line 8**	**w/o comp**	**SVC Bus 4**	**TCSC Line 8**
ELC	Generator Reliability	13.357	12.15	12.127	1.849	1.804	**1.785**
	Tr. Line Reliability	26.90	23.86	21.58	0.981	0.650	**0.633**
	Composite Reliability	2.941	2.429	2.231	0.052	0.047	**0.046**
EENS	Generator Reliability	422.19	420.93	416.50	257.52	251.25	**248.31**
	Tr. Line Reliability	950.32	842.65	720.77	352.59	343.75	**332.34**
	Composite Reliability	58.65	49.31	43.20	5.82	5.53	**5.42**
EDLC	Generator Reliability	3067.34	2907.09	2961.71	2208.79	1915.13	1951.61
	Tr. Line Reliability	9467.10	8828.65	8994.52	3565.05	2715.29	2767.01
	Composite Reliability	328.41	314.25	316.82	156.89	110.35	105.64
NLC	Generator Reliability	91.47	82.96	84.76	30.30	13.75	14.17
	Tr. Line Reliability	278.84	249.94	255.36	25.34	19.24	19.83
	Composite Reliability	64.25	55.41	57.66	15.55	13.76	14.29

Table 2: Reliability indices of RBTS system using algorithm SGA_PV and SGA_PV_FP

Type of reliability Indices	**Types of Reliability**	**SGA_PV**			**SGA_PV_FP**		
		w/o comp	**SVC Bus 3**	**TCSC Line 3**	**w/o comp**	**SVC Bus 6**	**TCSC Line 2**
ELC	Generator Reliability	0.2634	0.2263	0.1406	0.2462	0.2140	**0.1310**
	Tr. Line Reliability	15.28	14.98	12.80	12.97	12.77	**11.90**
	Composite Reliability	89.587	56.760	51.03	56.66	32.91	**30.35**
EENS	Generator Reliability	0.6130	0.5277	0.3277	0.5733	0.5290	**0.2431**
	Tr. Line Reliability	32.8051	32.1443	27.5968	27.8860	27.3441	**25.5361**
	Composite Reliability	166.50	103.84	93.42	105.71	60.31	**55.33**
EDLC	Generator Reliability	210.16	205.28	201.43	206.34	161.26	194.11
	Tr. Line Reliability	4074.83	4055.90	3981.11	1889.52	1846.05	1818.05
	Composite Reliability	1395.31	1229.27	1206.79	699.31	666.63	653.91
NLC	Generator Reliability	90.12	88.05	86.40	88.51	69.16	83.30
	Tr. Line Reliability	3856.32	3735.80	2880.61	1787.91	1731.77	1335.11
	Composite Reliability	1442.98	1134.04	1257.92	725.75	615.58	680.42

SVC was connected individually to all possible location to determine the reliability indices and results are shown in table. Fixed penalty and fuzzy penalty was applied. And it is observed that reliability indices EENS improved when fuzzy penalty was applied.

TCSC was connected individually to all possible location one by one. It is observed that reliability indices EENS improved when fuzzy penalty was applied further than SVC compensation.

The results are shown in table 1, 2 and 3 for WSCC, RBTS and 24 Bus IEEE reliability test system respectively

From table it can be observed that expected load curtailment and expected energy not supplied is improved significantly when TCSC at line 2 is obtained using SGA_PV_FP. It shows that TCSC manages the reactive power and hence system parameters are also improved shown in figure 9 and Table 4.

Table 3: Reliability indices of IEEE 24 Bus system using algorithm SGA_PV and SGA_PV_FP

Type of reliability Indices	**Types of Reliability**	**SGA_PV**			**SGA_PV_FP**		
		w/o comp	**SVC**	**TCSC**	**w/o comp**	**SVC**	**TCSC**
			Bus 8	**Line 1**		**Bus 10**	**Line 2**
ELC	Generator Reliability	64.01	59.49	52.07	60.32	34.94	**32.44**
	Tr. Line Reliability	593.56	434.28	308.17	518.72	157.02	**112.19**
	Composite Reliability	24.10	15.69	10.79	18.77	15.09	**7.60**
EENS	Generator Reliability	123.14	118.82	100.88	113.43	65	63.66
	Tr. Line Reliability	1303.44	934.85	660.79	1125.31	334.97	**240.44**
	Composite Reliability	33.51	26.34	21.78	29.86	30.01	**15.58**
EDLC	Generator Reliability	149.02	139.50	100.88	163.12	146.60	149.46
	Tr. Line Reliability	1354.66	1381.36	1369.23	1371.92	1352.38	1378.15
	Composite Reliability	123.46	73.16	82.56	110.11	84.24	67.60
NLC	Generator Reliability	79.34	79.34	74.25	81.44	72.24	79.38
	Tr. Line Reliability	622.25	633.21	631.85	622.21	619.92	631.84
	Composite Reliability	68.90	46.91	48.89	56.32	63.29	33.05

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6.1.2 Effects on bus voltages

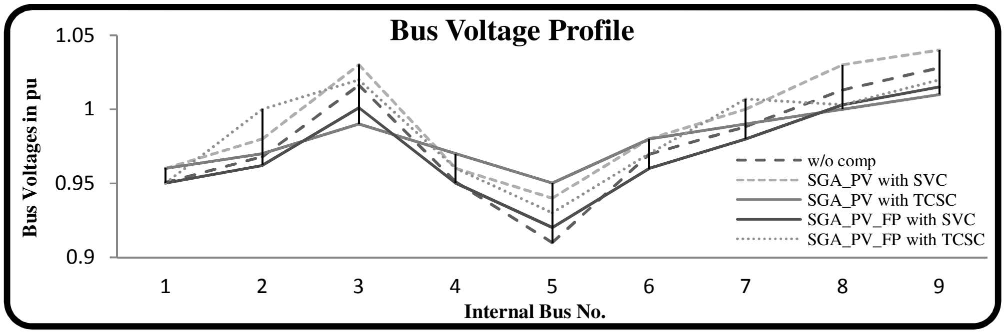

Figure 9: Voltage profile of WSCC system under G1 contingent condition using proposed algorithms

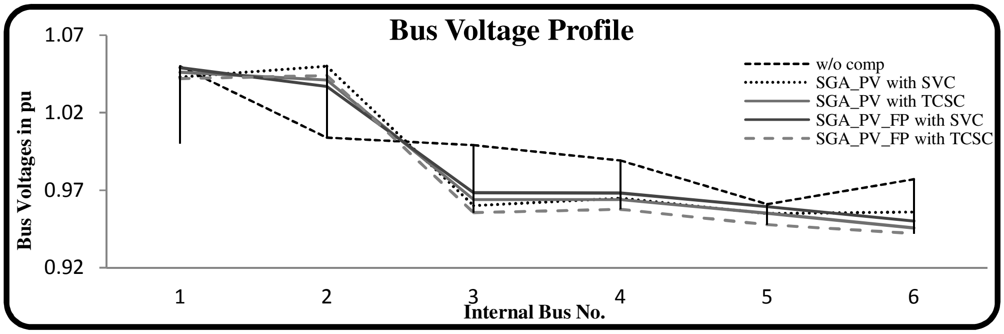

Figure 10: Voltage profile of RBTS system under T1 contingent condition using proposed algorithms

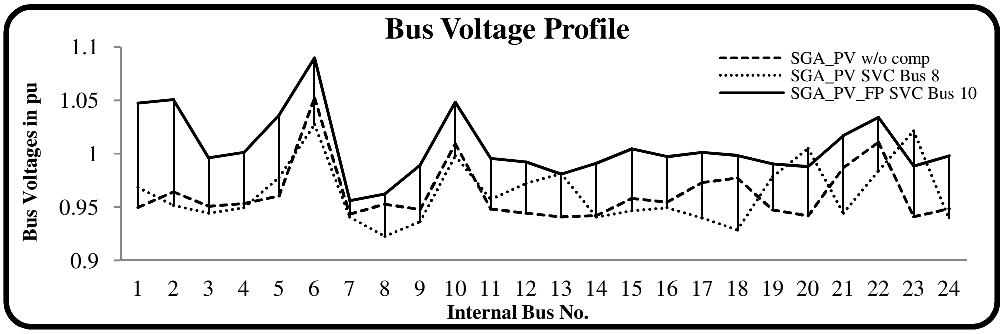

Figure 11: Voltage profile of IEEE system under T16 and T17 contingent condition using proposed algorithms with SVC compensation

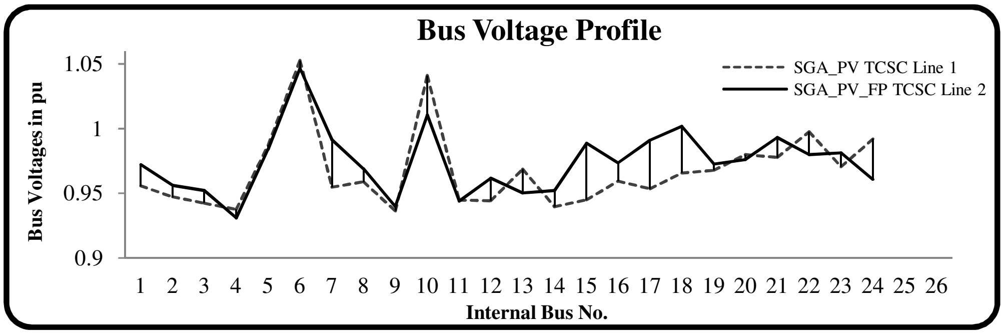

Figure 12: Voltage profile of IEEE system under T16 and T17 contingent condition using proposed algorithms with TCSC compensation

Figure 9, 10, 11 and 12 shows the bus voltage of WSCC, RBTS and IEEE system respectively using proposed algorithms with SVC and TCSC. From above figure it is observed that most of the bus voltages are within their specified limits of ±5%.

It is also observed that there is significant improvement in bus voltages when fuzzy penalty is applied.

Table 4: Real Power Flow of WSCC system obtained using proposed algorithms

Tr. Line No	**w/o comp**	**SVC**		**TCSC**	
		SGA_PV	**SGA_PV_FP**	**SGA_PV**	**SGA_PV_FP**
T1	0.00	0.00	0.00	0.00	0.00
T2	-0.30	-0.32	-0.07	-0.11	-0.19
T3	-1.17	-1.11	-0.93	-1.19	-0.93
T4	1.28	1.28	1.26	1.28	1.25
T5	-0.06	-0.11	-0.29	-0.03	-0.27
T6	0.31	0.37	0.71	0.40	0.70
T7	1.92	1.92	1.92	1.92	1.92
T8	-1.52	-1.47	-1.15	-1.44	-1.16
T9	0.31	0.33	0.15	0.12	0.19

RLPF- Real Line Power Flow

Table 4: Real Power Flow of RBTS system obtained using proposed algorithms

Tr. Line No	**w/o comp**	**SVC**		**TCSC**	
		SGA_PV	**SGA_PV_FP**	**SGA_PV**	**SGA_PV_FP**
T1	0	0	0	0	0
T2	0.421	0.421	0.421	0.432	0.708
T6	0.856	0.856	0.874	0.853	0.85
T7	0.421	0.421	0.421	0.432	0.216

RLPF- Real Line Power Flow

Table 4: Real Power Flow of IEEE- RTS system obtained using proposed algorithms

TL. No.	**RLPF**	**TL. No.**	**RLPF**	**TL. No.**	**RLPF**	**TL. No.**	**RLPF**
T1	0.5	T11	-0.25	T21	-1.58	T31	-0.59
T2	-0.27	T12	-0.46	T22	-2.03	T32	-0.79
T3	0.42	T13	0.12	T23	-1.42	T33	-0.79
T4	0.05	T14	-0.11	T24	-0.69	T34	-1.32
T5	0.42	T15	-1.07	T25	-0.66	T35	-1.32
T6	0.15	T16	-1.58	T26	-0.66	T36	-1.39
T7	-0.67	T17	0	T27	0.68	T37	-1.39
T8	-0.54	T18	-1.13	T28	-0.19	T38	-0.7
T9	0.31	T19	-0.57	T29	-2.02		
T10	-0.53	T20	0.5	T30	0.41		

RLPF- Real Line Power Flow

Table 4, 5 and 6 represents the real power flow of WSCC, RBTS and IEEE-RTS system respectively. From table 4 and 5 it can be observed that the line power flow using fuzzy penalty with TCSC is reduced as compared to fixed penalty with and without SVC

6. CONCLUSION

Study presented in this paper evaluates the generator, transmission line and composite system reliability indices evaluated for WSCC, RBTS and IEEE-TRS system with and without fuzzy penalty using GA based priority load curtailment. The effects of GA based priority based load curtailment are used to evaluate reliability indices and the system parameter using AC OPF with SVC and TCSC. Result show that TCSC the reactive power and improves the reliability indices and fuzzy penalty improves the system parameters.

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