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Improvement In Reliability Of Composite Power System Using Tcsc, Upfc Of 6 Bus Rbts – A Comparison

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Abstract : *Emerging techniques for composite power system reliability evaluation mainly focus on conventional generation and transmission facilities. Reliability analysis of composite power system is determined by applying the FACTS devices like UPFC & TCSC in IEEE 6 Bus RBTS system at different buses & transmission lines. In this paper, a comparison is carried out between the systems using UPFC, TCSC in order to describe which FACTS device is best suitable for the system. The comparison is made in different parameters via. availability & unavailability, System Indices, Probability of Failure & Expected Energy Not Supplied (EENS), by considering different modules & bus numbers of the composite power system*.
Keywords - *UPFC, TCSC, Reliability, EENS, Probability of Failure, System Indices.*

I. INTRODUCTION

Flexible AC transmission System (FACTS) technology is the ultimate tool for getting the most out of existing equipment via faster control action and new capabilities. The most striking feature is the ability to directly control transmission line flows by structurally changing parameters of the fast switching.

Unified Power Flow Controllers (UPFC) [1] is the most versatile FACTS [2] device that has emerged for the control and optimization of power flow in electrical power transmission systems [3-5]. It offers major potential advantages for static and dynamic operation [6-8] of transmission lines since it combines the features of both the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). Thyristor Controlled Series Capacitor (TCSC) is an important FACTS component which makes it possible to vary the apparent impedance of a specific transmission line so as to force power flow along a path. This controlled impedance [1] can be programmed to react in a planned way to contingencies so as to greatly enhance power system security.

In this paper, the impact of UPFC, TCSC on composite electric power system reliability is examined for 6 bus RBTS. FACTS devices are employed in a system to adjust the transmission infeed impedances and therefore, increase the transmission system capacity without increasing the system fault current levels. Load Point Indices, System Indices, Probability of Failure & EENS performances are presented to examine the impact of FACTS devices on the 6 bus RBTS test systems..

II. RELIABILITY INDICES

In a more practical network there are a number of load points and each point has a distinct set of reliability indices. The basic parameters are the probability & frequency of failure at the individual load points, but additional indices can be created from these generic values. The individual load point indices can also be aggregated to produce system indices which include, in addition to consideration of generation adequacy, recognition of the need to move the generated energy through the transmission network to the customer load points.

It is important to appreciate that, if these indices are calculated for a single load level and expressed on a base of one year, they should be designated as *annualized* values. Annualized indices calculated at the system peak load level are usually much higher than the actual annual indices.

A. Load Point Indices:

The following are the expressions [4] to determine the load point indices of the given system

$$\text{Probability of Failure} = \sum_j P_j P_{kj} \quad (1)$$

$$\text{Frequency of Failure} = \sum_j F_j P_{kj} \quad (2)$$

$$\text{Expected Load Curtailed} = \sum_j L_{kj} F_j (\text{MW}) \quad (3)$$

$$\text{EENS} = \sum_j L_{kj} P_j * 8760(\text{MWh}) \quad (4)$$

where: j is an outage condition in the network
P_j is the state probability of the outage event j
F_j is frequency of occurrence of the outage event j
P_{kj} is the probability of load curtailment at bus k during outage event j
L_{kj} is the load curtailment at bus k during outage event j
D_{kj} is the duration in hours of load curtailment at bus k during outage event.

B. System Indices:

$$\text{Bulk Power Supply Disturbances (BPSD)} = \sum_k \sum_j F_j \quad (5)$$

$$\text{Bulk Power Interruption Index (BPII)} = \frac{\sum_k \sum_j L_{kj} F_j}{L_s} \quad (6)$$

$$\text{Bulk Power Energy Curtailment Index (BPECI)} = \frac{\sum_k \sum_j 60 * L_{kj} D_{kj} F_j}{L_s} \quad (7)$$

Where L_s is the total system load

III. RELIABILITY STUDY RESULTS

The reliability evaluation of a composite power system involves four key steps:
1. Reliability modeling of the generation & transmission units
2. Enumeration of all possible system contingencies
3. Determination of load curtailment under each contingency and
4. Calculation of the reliability indices at each load point.

First & third steps have been extended in order to incorporate FACTS in the overall evaluation.

Reliability analysis of IEEE 6 bus RBTS is determined by applying the FACTS devices like UPFC, TCSC in the system at different buses & transmission lines. In order, to describe which FACTS device is best suitable for the system, a comparison is carried out between the systems with UPFC, TCSC in various ascepts.

3.1 Comparison with respect Availability & Unavailability

Availability & unavailability of the system when using UPFC, TCSC are calculated individually [2, 4]. A comparison is made between the two FACTS elements of the system which is shown in Table 1 when using different modules. The graphical representation of Table 1 is shown in Fig. 1 & 2

Table 1: Availability & Unavailability of UPFC, TCSC with different Modules

Modules	Availability		Unavailability	
	UPFC	TCSC	UPFC	TCSC
2	0.99818	0.995371	0.00182	0.004629
3	0.99623	0.994594	0.00377	0.005406
4	0.99462	0.993628	0.00538	0.006372
5	0.99374	0.992594	0.00626	0.007406
6	0.99246	0.991834	0.00754	0.008166
7	0.99164	0.990346	0.00836	0.009654
8	0.98254	0.980671	0.01746	0.019329

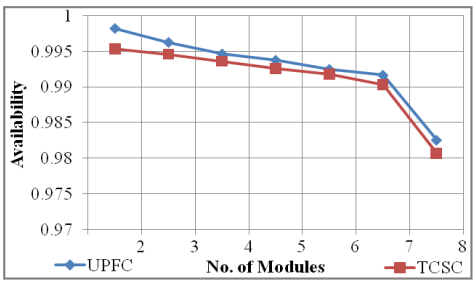

Fig. 1: Availability of FACTS vs No. of Modules

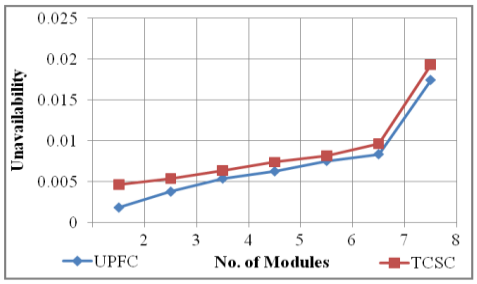

Fig. 2: Unavailability of FACTS vs Module No.

3.2. Comparison with respect to System Indices:

System Indices like BPSD, BPII & BPECI for 6 bus RBTS are calculated by applying different modules of FACTS devices.

i. BPSD (Bulk Power Supply Disturbances)

A comparison for BPSD are determined in Table 2 when using UPFC, TCSC in the given system & demonstrated in Fig. 3

Table 2: Comparison of BPSD with different modules of UPFC & TCSC

Module. No.	UPFC	TCSC
2	19.69	17.54
3	19.58	17.17
4	19.47	16.85
5	19.39	16.58
6	19.31	16.51
7	19.26	16.62
8	19.38	16.84

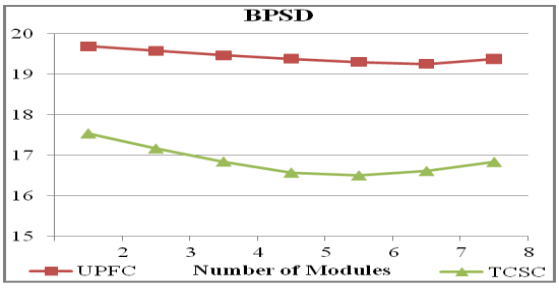

Fig 3: BPSD vs Module No.

ii. BPII (Bulk Power Interruption Index)

A comparison for BPII are determined in Table 3 when using UPFC, TCSC in the given system & demonstrated in Fig. 4

Table 3: Comparison of BPII with Module No.

Module No.	UPFC	TCSC
2	0.3642	0.3462
3	0.363	0.3458
4	0.3622	0.3451
5	0.3612	0.345
6	0.361	0.3448
7	0.359	0.3452
8	0.364	0.3456

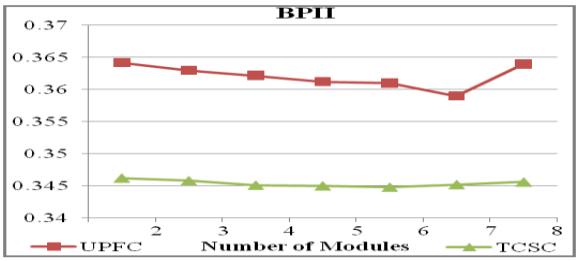

Fig 4: BPII vs Module No.

iii. BPECI (Bulk Power Energy Curtailment Index)

A comparison for BPECI are determined in Table 4 when using UPFC, TCSC in the given system & demonstrated in Fig. 5

Table 4: Comparison of BPECI with Module No.

Module No.	UPFC	TCSC
2	331.14	284.36
3	331.11	284.01
4	331.08	283.92
5	331.04	283.87
6	330.91	283.85
7	330.69	283.88
8	331.01	283.91

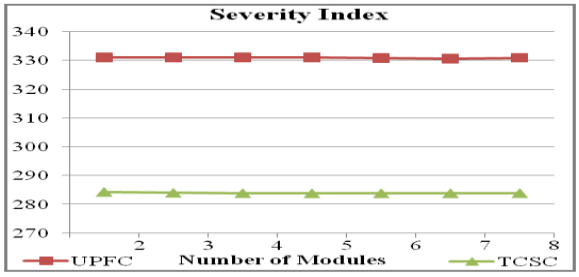

Fig 5: BPECI vs Module No.

Similarly the system indices are also calculated with respect to the generation capacity, load demand when using TCSC, UPFC and when not using TCSC, UPFC. The corresponding values are represented in Table 5 & 6 and graphically represented in Fig. 6, 7 & 8 respectively

Table 5: SI (with & w/o TCSC) vs Generation Capacity

Gen. Cap. (MW)	Load (MW)	BPSD		BPII		Severity Index	
		W/o TCSC	With TCSC	W/o TCSC	With TCSC	W/o TCSC	With TCSC
240	185	14.76	14.35	0.274	0.246	264.66	259.86
270	203.5	14.98	14.57	0.286	0.261	272.34	263.66
300	222	15.63	15.02	0.297	0.269	276.93	268.71
330	240.5	17.24	16.72	0.308	0.283	278.11	271.93
345	259	24.11	20.63	0.395	0.315	294.63	288.32
360	277.5	68.73	28.146	0.632	0.364	563.66	297.64

Table 6: SI (with & w/o UPFC) vs Generation Capacity

Gen Cap (MW)	Load (MW)	BPSD		BPII		Severity Index	
		W/o UPFC	With UPFC	W/o UPFC	With UPFC	W/o UPFC	With UPFC
240	185	19.83	19.42	0.364	0.324	329.642	328.52
270	203.5	19.89	19.67	0.372	0.334	331.246	330.12
300	222	20.65	20.31	0.379	0.351	333.201	331.92
330	240.5	21.84	21.24	0.389	0.360	336.721	332.67
345	259	34.19	23.15	0.465	0.378	371.264	333.16
360	277.5	78.67	29.73	0.913	0.389	615.259	334.25

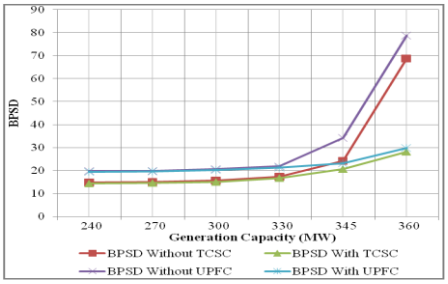

Fig 6: System Indices (BPSD) vs Generation Capacity

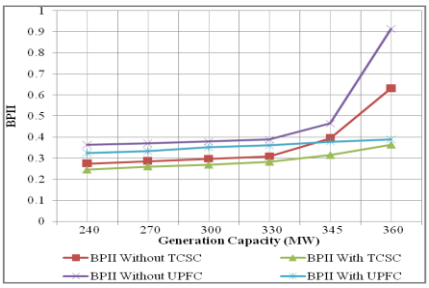

Fig 7: System Indices (BPII) vs Generation Capacity

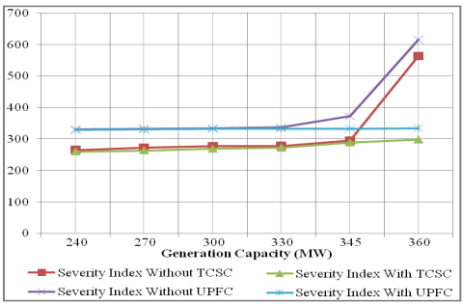

Fig 8: System Indices (BPECI) vs Generation Capacity

3.3 Comparison with respect Probability of Failure & EENS

Probability of Failure & EENS are one of the important parameters to determine the relibility analysis of the given system. Probability of Failure & EENS for 6 bus RBTS are calculated at each and every bus by applying different modules of FACTS devices. A comparison for Probability of Failure & EENS are determined in Table 7 when considering 7 modules of UPFC, TCSC at all the 6 buses & demonstarted in Figs. 9 & 10. Similarly, A comparison for Probability of Failure & EENS are also detremined in Tables 8, 9, 10, 11 & 12 respectively when using different modules of UPFC, TCSC at all the 6 buses in the given system & demonstrated in Figs. 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21 & 22 respectively.

Table 7: Probability of Failure & EENS vs Bus Number

Bus No.	Probability of Failure		EENS	
	UPFC	TCSC	UPFC	TCSC
1	0.0081547	0.008411	124.64	129.94
2	0.0082665	0.008463	88.082	99.98
3	0.0083131	0.008458	377.731	395.43
4	0.0083139	0.008456	177.28	183.94
5	0.0083145	0.008457	88.86	97.58
6	0.0084512	0.008472	288.36	298.66

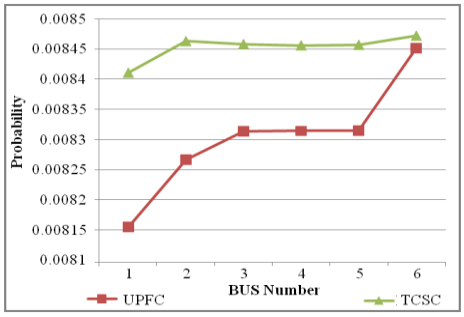

Fig 9: Probability of Failure Comparison between UPFC & TCSC vs Bus No. of 6 bus RBTS

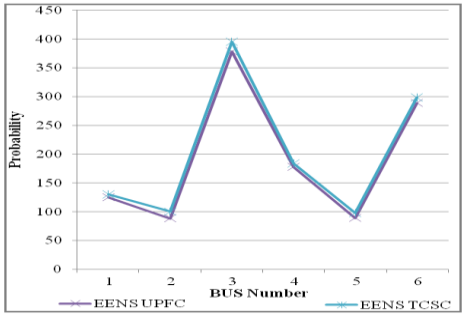

Fig 10: EENS Comparison between UPFC & TCSC vs Bus No. of 6 Bus RBTS

Table 8: Probability of Failure at Bus 1&2 vs Mo. No

Mo No.	Bus No. 1		Bus No. 2	
	UPFC	TCSC	UPFC	TCSC
2	0.008232	0.008536	0.008363	0.008516
3	0.008215	0.008511	0.008348	0.008507
4	0.008194	0.008459	0.008331	0.008498
5	0.008179	0.008416	0.008316	0.008491
6	0.008158	0.008411	0.008292	0.008463
7	0.008154	0.008417	0.008266	0.008475
8	0.008162	0.008426	0.008297	0.008494

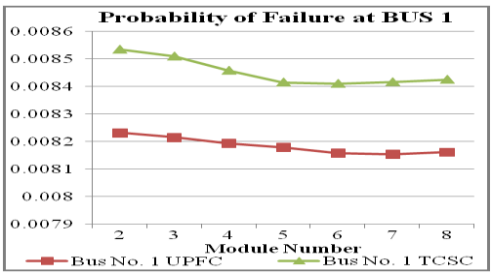

Fig 11: Probability of Failure at Bus 1 vs Module No.

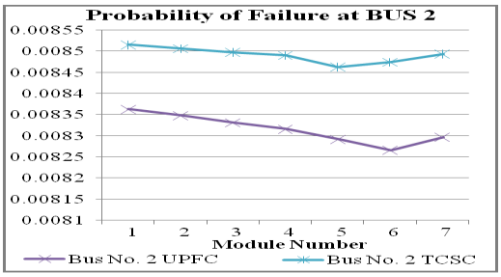

Fig 12: Probability of Failure at Bus 2 vs Module No.

Table 9: Probability of Failure at Bus 3 & 4 vs Mo. No

Module No.	Bus No. 3		Bus No. 4	
	UPFC	TCSC	UPFC	TCSC
2	0.008141	0.008513	0.008137	0.008511
3	0.008167	0.008501	0.008162	0.008498
4	0.008248	0.008489	0.008245	0.008486
5	0.008281	0.008481	0.008275	0.008479
6	0.008307	0.008458	0.008306	0.008456
7	0.008313	0.008474	0.008313	0.008472
8	0.008301	0.008496	0.008302	0.008494

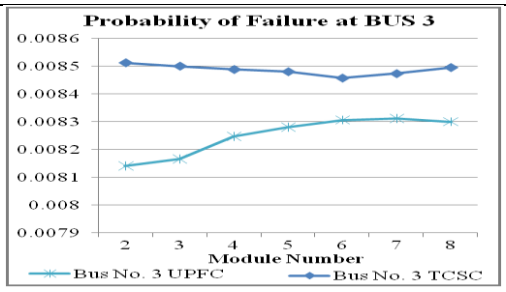

Fig 13: Probability of Failure at Bus 3 vs Module No.

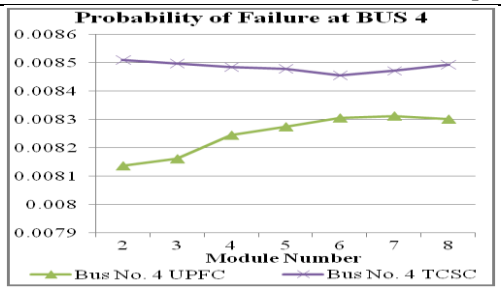

Fig 14: Probability of Failure at Bus 4 vs Module No.

Table 10: Probability of Failure at Bus 5 & 6 vs Mo. No.

Module No.	Bus No. 5		Bus No. 6	
	UPFC	TCSC	UPFC	TCSC
2	0.008142	0.008507	0.008634	0.00876
3	0.008171	0.008496	0.008602	0.00886
4	0.008252	0.008489	0.008562	0.00894
5	0.008281	0.008480	0.008511	0.00907
6	0.008307	0.008457	0.008472	0.00925
7	0.008314	0.008470	0.008489	0.00945
8	0.008306	0.008491	0.008496	0.00916

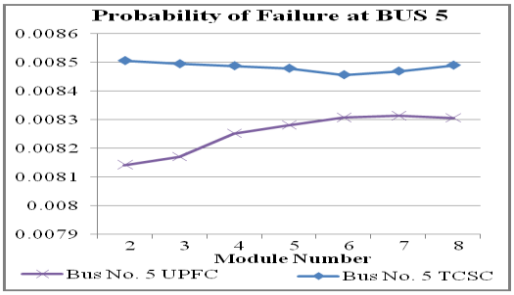

Fig 15: Probability of Failure at Bus 5 vs Module No.

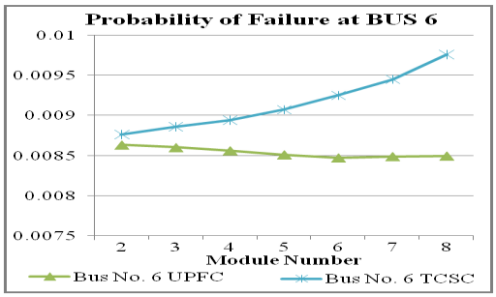

Fig 16: Probability of Failure at Bus 6 vs Module No.

Table 11: EENS at Bus 1, 2 & 3 vs Module No.

Mo No.	Bus No. 1		Bus No. 2		Bus No. 3	
	UPFC	TCSC	UPFC	TCSC	UPFC	TCSC
2	126.21	132.64	89.21	102.34	377.86	398.64
3	125.94	132.12	88.81	101.96	377.35	398.14
4	125.54	131.54	88.39	101.12	376.94	397.58
5	125.12	131.08	88.12	100.78	376.61	396.91
6	124.65	129.94	87.88	99.98	376.21	395.43
7	123.97	130.16	87.68	100.36	375.92	396.16
8	124.21	130.84	87.91	101.03	376.14	396.88

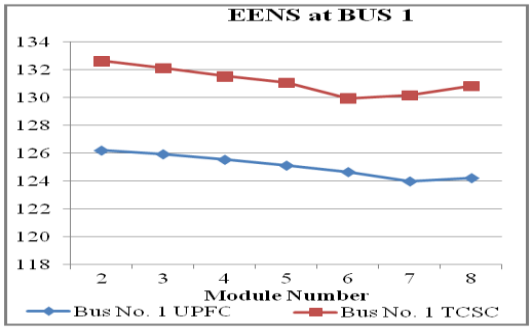

Fig 17: EENS at Bus 1 vs No. of Modules

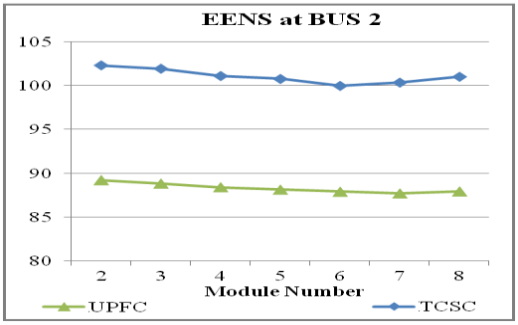

Fig 18: EENS at Bus 2 vs No. of Modules

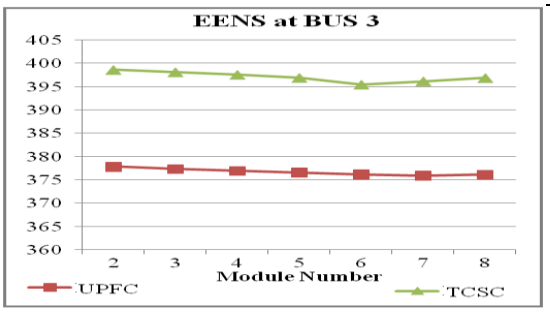

Fig 19: EENS at Bus 3 vs No. of Modules

Table 12: EENS at Bus 4, 5 & 6 vs Module No.

Mo No.	Bus No. 4		Bus No. 5		Bus No. 6	
	UPFC	TCSC	UPFC	TCSC	UPFC	TCSC
2	178.38	186.42	90.68	100.24	290.34	302.84
3	177.97	185.96	90.31	99.38	289.97	301.63
4	177.69	185.13	89.81	98.66	289.34	300.75
5	177.26	184.66	89.42	97.81	288.94	299.54
6	176.94	183.94	88.93	97.58	288.56	298.66
7	176.54	184.52	88.49	98.12	287.99	299.18
8	176.85	185.66	88.81	99.42	288.31	300.11

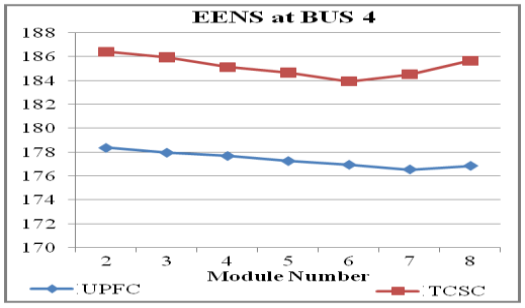

Fig 20: EENS at Bus 4 vs Module No.

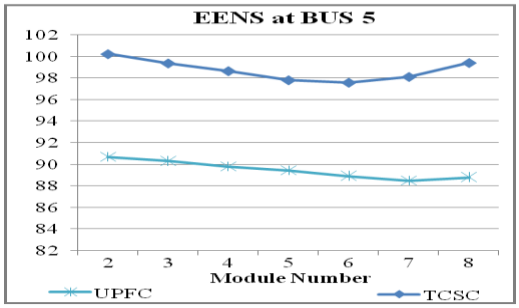

Fig 21: EENS at Bus 5 vs No. of Modules

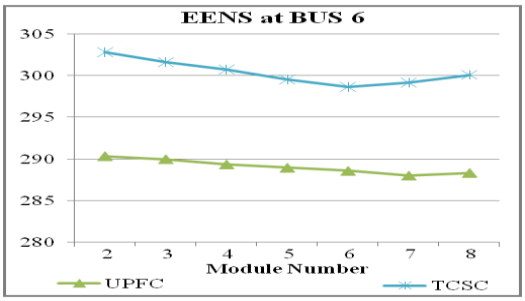

Fig 22: EENS at Bus 6 vs No. of Modules

IV. CONCLUSION

In this paper, comparison has been made between TCSC & UPFC using for 6 bus RBTS composite power system in different aspects like, Availability & unavailability, System Indices, Probability of failure and EENS. From the above results, major improvement can be observed in the system when using different modules (7) of UPFC rather than TCSC at all the buses in the system. 20% of energy has been recovered by UPFC when compared with TCSC in the parameter of EENS.

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