International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-12 Issue-5, June 2023

Reliability Improvement of Composite Power System using UPFC

E. Sreeshobha, E. Vidyasagar

Abstract: ***Together with quality power supply criteria, Composite Power System (CPS) reliability is also one of the important aspects of deciding the security of the CPS for a given load demand. In the current paper, the reliability of CPS is evaluated. The Newton Raphson (NR) approach is implemented in Power System Simulation for Engineering (PSSE) software to take into account, the load flows, then the power available to the load points, to evaluate the reliability of CPS. Newton Raphson NR Method was implemented by considering different contingencies of the CPS. Power available to the load points obtained by the NR method is critical in identifying the successful operating state of the CPS. Expected Load Curtailment (ELC), Number of Load Curtailment (NLC), Expected Energy Not Supplied (EENS), and Severity Index (SI) are the crucial dependability indices that are assessed. The main objective of the Reliability evaluation of the CPS is to investigate the scope for the improvement of reliability and explore the possible schemes to improve CPS reliability. The Unified Power Flow Controller (UPFC) one of the Flexible AC Transmission Systems is incorporated into the CPS to analyze the improvement in the reliability of the system. Further, the effect of UPFC on the power-carrying capacity of the lines under contingency conditions, resulting in the failure mode of CPS operation is examined. Improvement in the reliability indices of the system is observed due to UPFC incorporation.***

Keywords: ***Composite Power System, EENS, Reliability, UPFC***

I. INTRODUCTION

The primary goal of the power system is to supply the electric load with more reliable power. To meet this the three primary functional zones of the power system the generation, transmission, and distribution systems must be planned properly [1][2]. Transmission and generation systems are referred to as the composite power system [3 - 5]. To conduct the reliability study, with and without UPFC a three-bus system consisting of two generating plants and one load point, as indicated in Figure 1, is taken into consideration. The reliability of a CPS was studied by using certain indices like Availability (A), Unavailability (U), probability of failure(Q_k), Expected Load Curtailment (ELC), Number of Load Curtailments(NLC), Expected Energy Not Supplied (EENS), Severity Index (SI). The generators and/or transmission lines, outage will affect the reliability of the power system. The equations 1 to 7 show the quantitative reliability indices of the composite power system.

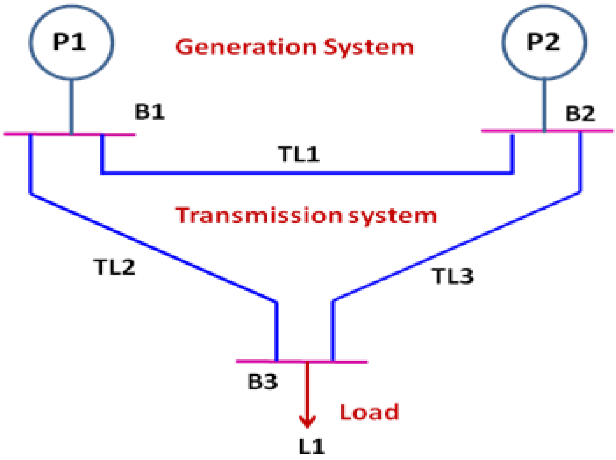

Figure 1. Schematic diagram of three bus CPS

Availability and unavailability of a component or state of a system are a function of failure rate and repair rates.

$$\text{Availability } A = \frac{\mu}{\lambda+\mu} \quad (1)$$

$$\text{Unavailability } U = \frac{\lambda}{\lambda+\mu} \quad (2)$$

Probability of failure: Probability of load exceeding, the maximum load that can be supplied during an outage by the system.

$$Q_k = \sum P_j P_{kj} \quad (3)$$

where "j" is an outage condition in the network, P_j = Probability of existence of an outage, and P_{kj} = Probability of load at bus k, exceeding the maximum load that can be supplied at that bus during the outage "j".

Expected Load Curtailed (ELC): Magnitude of the load at the k^{th} bus, which is not supplied by the system, due to contingency.

$$ELC = \sum_{j \in x,y} L_{kj} F_j \quad \text{(MW)} \quad (4)$$

Expected Number of Load Curtailments (NLC): Total number of loads curtailed due to the contingencies resulting in system failure.

Manuscript received on 28 May 2023 | Revised Manuscript received on 04 June 2023 | Manuscript Accepted on 15 June 2023 | Manuscript published on 30 June 2023.
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$$NLC = \sum_{j \in x,y} F_j \qquad (5)$$

$j \in x$ includes all contingencies resulting in line overloads, which are alleviated by load curtailment at bus K, and $j \in y$ includes all contingencies which result in isolation of bus K.

Expected Energy Not Supplied (EENS): Magnitude of the energy that could not be supplied to the load due to the contingencies, which results in system failure.

$$EENS = \sum_{j \in x,y} L_{kj} D_{kj} F_j \quad (MWh) \qquad (6)$$

D_{Kj} is the duration (in hours), of the load curtailment at an isolated bus K due to the outage " j ".

Severity Index

$$SI = \frac{\sum_k \sum_{j \in x,y} L_{kj} D_{kj} F_j}{L_S} \quad \text{(MWh /MW-yr)} \qquad (7)$$

Ls = Total system load

Incorporation of UPFC will modify some of the failure mode outages i.e. $P_{kj} = 1$ into $P_{kj} = 0$ i.e. successful mode of operation by improving the power carrying capacity of the transmission lines. Based on the P_{kj} value, all reliability indices of the system will change. For every outage of the generator and /or transmission line, rerouting of the power occurs in the transmission system, which will lead to overloading of the transmission lines [6-11]. It is required to improve the power-carrying capacity of the transmission lines to overcome the overloading effect and to meet the load demand to have the reliable operation of the composite power system. One of the methods to improve the power carrying capacity of the transmission lines [12 - 19], to meet the load demand, to achieve a reliable operation, is incorporating/connecting the UPFC. The effect of the UPFC on the reliability of the CPS is presented in the following sections. The reliability of the three-bus system by Load Flow based method is analyzed in section II. The performance of the power system by incorporating UPFC is examined in section III. Comparative analysis in the form of results is shown in section IV. Conclusions and references are presented in V and VI sections respectively.

II. RELIABILITY EVALUATION BY LOAD FLOW-BASED METHOD

The three-bus system configuration shown in Figure 1, is the case study considered for the analysis of the reliability with and without UPFC. The analysis presented in this paper can be extended to any larger configuration of the CPS. The configuration [20 - 21] of the case study - three bus CPS is tabulated in Table 1. The three-bus system is simulated in PSSE, to obtain the power flows through the transmission lines [22]. The base case simulation diagram is shown in Figure 2. By introducing the outage conditions of the generating units and transmission lines, using Newton Raphson method power flowing through each line and power available to the load at each outage state is obtained by simulation. Power supplied to the load for certain outage states is differing from that of the power available to the load with the traditional method.

Table 1: Case study Three bus system configuration

Generation data					
Plant	No. of Generators	The capacity of each generator (MW)	The average Failure rate of each Getor (failures/ year) (λ)		Average Repair rate of each Generator (repairs/ year) (μ)
P1	4	20	1		99
P2	2	30	3		57
Transmission Line data					
Transmission line	From bus	To bus	Capacity (MW)	Average Failure rate (failures/year)	Average Repair rate (repairs/year) (μ)
L_1	1	2	20.5	4	1095
L_2	1	3	74.5	5	1095
L_3	2	3	65.5	3	876
Load data					
Load	110 MW				

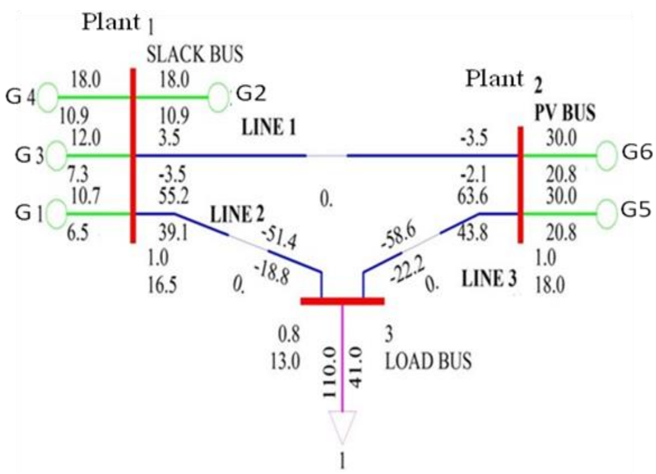

Figure 2: Load flow single line diagram for the base case

Considering the new values of power available to the load, referring to equations 1 to 7, the reliability indices of the CPS are evaluated as indicated in Table 2. The total eight outage states corresponding to $P_{kj} = 1$ are the failure mode outage of the system into $P_{kj} = 0$

Retrieval Number:100.1/ijeat.E41980612523
DOI: 10.35940/ijeat.E4198.0612523
Journal Website: www.ijeat.org

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Table 2: load flow based reliability indices of CPS

Outages	Power Supplied to the load	P_j Probability	Departure rate	Frequency	P_{Kj}	D_{Kj} (hours)	L_{Kj} (MW)	ELC (MW)	NLC	EENS (MWh)	EDLC (hours)
No outages	110	0.856921582	22	18.852275	0	398.1818	0	0	0	0	0
G_1	110	0.035027794	120	4.2033353	0	73	0	0	0	0	0
G_1, G_2	110	0.00053072	218	0.1156979	0	40.18349	0	0	0	0	0
G_1, G_5	110	0.003687136	174	0.6415617	0	50.34483	0	0	0	0	0
G_1, L_1	110	0.00012749	121	0.0154263	0	72.39669	0	0	0	0	0
G_1, L_2	0.2	0.000159217	1210	0.1926529	1	7.239669	109.8	21.15328	0.192653	153.142789	1.394743
G_1 L_3	24.8	0.000119549	993	0.1187119	1	8.821752	85.2	10.11426	0.118712	89.2254745	1.047247
G_5	110	0.091256621	76	6.9355032	0	115.2632	0	0	0	0	0
G_5, G_6	97.8	0.00240149	130	0.3121937	1	67.38462	12.2	3.808763	0.312194	256.652042	21.03705
G_5, L_1	101.9	0.000332144	1167	0.3876123	1	7.506427	8.1	3.13966	0.387612	23.5676244	2.909583
G_5, L_2	0.2	0.000414803	1166	0.4836601	1	7.512864	109.8	53.10588	0.48366	398.977265	3.633673
G_5, L_3	24.8	0.000311456	949	0.2955718	1	9.230769	85.2	25.18272	0.295572	232.455841	2.728355
L_1	110	0.00315537	1113	3.5119268	0	7.87062	0	0	0	0	0
L_2	0.2	0.003940627	1112	4.381977	1	7.877698	109.8	481.1411	4.381977	3790.28402	34.51989
L_3	24.8	0.002958832	895	2.648155	1	9.787709	85.2	225.6228	2.648155	2208.33049	25.91937
					8			823.2684	8.820535	7152.63555	93.18992

III. RELIABILITY EVALUATION BY THREE BUS SYSTEM BY UPFC INCORPORATION

The system may more easily adapt to changing conditions brought on by outages and provide stable operating conditions by using dynamic active and reactive power regulation with power electronic converters. One of the FACTS controllers, UPFC, will establish independent and/or simultaneous control of active and reactive power flows in the transmission lines to provide power availability to the load. Figure 3 shows the PSSE simulation diagram of the CPS by incorporating UPFC. The reliability of the three bus system is examined by incorporating UPFC between bus 2 and bus 3 as shown in Figure 3. The modified power available to the load for outage conditions and related reliability indices is tabulated in Table 3.

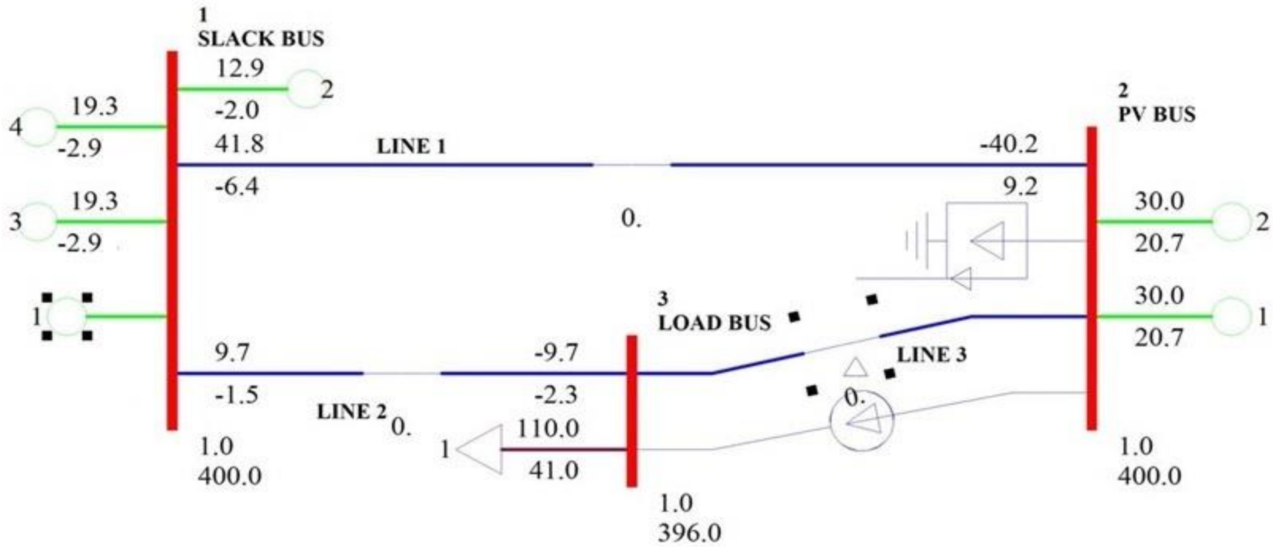

Figure 3: Three bus system with UPFC Load flow single line diagram of G_1L_3 outage state

Table 3: load flow based reliability indices of CPS with UPFC

Outages	Available capacity	P_j Probability	Departure rate	Frequency	P_{Kj}	D_{Kj} (hours)	L_{Kj} (MW)	ELC (MW)	NLC	EENS (MWh)	EDLC (hours)
No outages	110	0.856922	22	18.85227	0	398.1818	0	0	0	0	0
G_1	110	0.035028	120	4.203335	0	73	0	0	0	0	0
G_1, G_2	110	0.000531	218	0.115698	0	40.18349	0	0	0	0	0
G_1, G_5	110	0.003687	174	0.641562	0	50.34483	0	0	0	0	0

Retrieval Number:100.1/ijeat.E41980612523
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G_1, L_1	110	0.000127	121	0.015426	0	72.39669	0	0	0	0	0
G_1, L_2	0.2	0.000159	1210	0.192653	1	7.239669	109.8	21.15328	0.192653	153.1428	1.394743
G_1 L_3	110	0.00012	993	0.118712	0	8.821752	0	0	0	0	0
G_5	110	0.091257	76	6.935503	0	115.2632	0	0	0	0	0
G_5, G_6	97.8	0.002401	130	0.312194	1	67.38462	12.2	3.808763	0.312194	256.652	21.03705
G_5, L_1	101.9	0.000332	1167	0.387612	1	7.506427	8.1	3.13966	0.387612	23.56762	2.909583
G_5, L_2	0.2	0.000415	1166	0.48366	1	7.512864	109.8	53.10588	0.48366	398.9773	3.633673
G_5, L_3	110	0.000311	949	0.295572	0	9.230769	0	0	0	0	0
L_1	110	0.003155	1113	3.511927	0	7.87062	0	0	0	0	0
L_2	0.2	0.003941	1112	4.381977	1	7.877698	109.8	481.1411	4.381977	3790.284	34.51989
L_3	110	0.002959	895	2.648155	0	9.787709	0	0	0	0	0
Recovered states					3			562.3487	5.758096	4622.624	63.49494

IV. RESULTS

Comparative analysis of the reliability analysis of the CPS, LFB method, and LFB method with UPFC are presented in Table 4. In the LFB method, outage states which are practically not feasible are eliminated and actual possible outage states are only considered for the reliability evaluation. With the LFB method accuracy is more.

Table 4: Unreliable operating states of CPS, with and without UPFC

LFB Method without UPFC				LFB Method with UPFC	
S. No	**outages**	**Power supplied to the load**	**P_{Kj}**	**Power supplied to the load**	**P_{Kj}**
1	base case	110	0	110	0
2	G_1	110	0	110	0
3	G_1, G_2	110	0	110	0
4	G_1, G_5	110	0	110	0
5	G_1, L_1	110	0	110	0
6	G_1, L_2	0.2	1	0.2	1
7	$G_{1,}$ L_3	24.8	1	110	0
8	G_5	110	0	110	0
9	G_5, G_6	97.8	1	97.8	1
10	G_5, L_1	101.9	1	101.9	1
11	G_5, L_2	0.2	1	0.2	1
12	G_5, L_3	24.8	1	110	0
13	L_1	110	0	110	0
14	L_2	0.2	1	0.2	1
15	L_3	24.8	1	110	0
Total states			15	15	
Generation less than load states			8		5

Due to the consideration of the exact power available to the load during outage conditions, the outage states causing failure mode of operation are eight. There is a reduction in outage states related to the failure mode of operation. So G1, G2; G1, G5, and G5 are three states up mode states, identified due to the LFB method. The incorporation of the UPFC system can deliver the load demand even under G_1, L_3; G_5, $L_{3,}$ and L3 outage states. There is a reduction in the outage states causing the failure of the system operation with and without UPFC of the LFB method respectively. Probability of failure(P), Expected Load Curtailed (ELC), Number of Load Curtailments, Expected Energy Not Supplied (EENS), Bulk Power Interruption Index (BPII), and Severity Index (SI) are the various reliability indices evaluated based on equations 1 to 7, for the three bus case study are tabulated in Table 5.

Table 5: Comparison of reliability indices with and without UPFC by LFB methods

S. No	Indices	LFB Method without UPFC	LFB Method with UPFC
1	Probability of failure (P)	0.01063	0.00724
2	Expected Load Curtailed (ELC) (MW)	823.26	562.34
3	Number of Load Curtailments	8.82	5.75
4	Expected Energy Not Supplied (EENS) (MWh)	7152.63	4622.62
6	Severity Index (SI) (MWh/MW-yr)	65.02	42.02

Retrieval Number:100.1/ijeat.E41980612523
DOI: 10.35940/ijeat.E4198.0612523
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

V. CONCLUSIONS

CPS reliability evaluation by the LFB approach is established for the Three bus system. The improvement of the system reliability is observed by the decrease in the probability of failure, as well as the minimal values of the Expected load curtailment (ELC), Number of Load Curtailments (NLC), Expected Energy Not Provided (EENS), and Severity Index (SI) indices. The UPFC integration detects an increase in system dependability by further lowering the reliability indices. The result of incorporating the UPFC is increased reliability.

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	No, the article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal participation in this article

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