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Analyzing Reliability of Tamil Nadu Power Grid for the Year 2015 using Wasp-IV

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Abstract

Reliability is the core element measure to be taken into account in electrical power system planning, design and in operation. This reliability of power system is viewed as the probability of providing uninterruptable/continuous power supply to the consumers in an efficient way meeting their load demand. The objective of this paper is to study, analyze and examine the reliability of Tamil Nadu power grid by accounting the load demand for the year 2015. For an effective and error free analysis of this reliability, generation reliability indices of Loss of Load Probability (LOLP) and Energy Not Served (ENS) are used as reliability deciding criteria. In accordance with the objective, the reliability analysis for the restricted peak demand of the state of Tamil Nadu for the year 2015 has been made using Wien Automatic System Planning IV (WASP IV). The Progress Report for 2015 issued by Southern Regional Power Committee is used for collecting official and authentic data for the study. Methodology for this study is formulated by applying Forced Outage Rate (FOR) at two different ways whereby reliability indices are analyzed. The study reveals that in the first approach FOR is hypothetical as per its commencement period of the plants, where as in second approach deals with approximate unavailability data. Attempt is made to improve the reliability in Tamil Nadu Power Grid by adapting to expected measures. This analysis is made by applying Demand Side Management (DSM) with the implementation of energy sufficient programs. The results showed that there is a reduction in the Loss of Load Probability and Energy Not Served when energy efficient program in demand side is adapted.

Keywords: Energy Not Served (ENS), Forced Outage Rate (FOR), Introduction, Loss of Load Probability (LOLP), Wien Automatic System Planning–IV (WASP-IV)

1. Introduction

The power system reliability is termed as the probability of providing continuous supply with a fixed /definite voltage and frequency within prescribed ranges around the nominal values. In a given process, power system's reliability reflects the performance of the system as a whole, in accordance with generation facilities as well as the transmission network and the distribution grid. The function of an electric power system is to provide electricity to its customers efficiently and with a reasonable assurance of continuity and quality[1]. Reliability is the probability measure of a device or a system performing its function adequately, for the period of time intended, under specified operating conditions[2]. In general, additional generation capacity increases the reliability and adds value to the service, but incurs additional cost as well. A modern power system, which is in practice conventionally, is complex, highly integrated and very large. Fortunately, this system can be divided into appropriate subsystems like generation, transmission and distribution. Quite for long, reliability studies are carried out individually and in combinations of these three areas of generation, transmission and distribution. For the purpose of innovative and contemporariness, the evaluation of generation reliability only is carried out in this work since it is assumed that the

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actual degree of reliability experienced by a customer will vary from region to region.

During the financial year 2010-2011, southern regions of India witnessed the highest ever demand for power of 10.5MU and continued power shortage[3]. From the data collected for the study, Reliability indices, Loss of Load Probability (LOLP) and Energy Not Served (ENS) for Tamil Nadu, in the year 2012 were calculated using WASP-IV[4]. There have been various levels of shortages observed from this analysis: LOLP was 74.3% in the same year. The state faced minimum peak shortage of 1.4% in August and September 2013 while the maximum peak demand shortage in January 2013 was 17.9%; and the minimum energy shortage in October 2013 was of 1.5% and in January 2013 maximum energy shortage was 21.7%[5].

The average peak demand and energy shortage for the year 2013 had been calculated as 8.19% and 10.5% respectively. Based on this calculation, a climate–oriented generation planning has been proposed for Tamil Nadu[6]. For the sake of comparative analysis the performance of various plants in Tamil Nadu was analyzed for the period[7] 2004-2008. In addition, the installed capacity of all the generating plants in Tamil Nadu was derived during the study[8]. At the end of year 2014, Tamil Nadu had 7206 MW installed wind power generation capacity whereas at the end of 2015 it should be increased to 7394 MW.

In Tamil Nadu, two kinds of load demands are taken into account-restricted demand and un-restricted demand. In this paper, restricted demands are considered with two cases. In both the cases two different Forced Outage Rates (FOR) of the plants are assumed and reliability indices LOLP and ENS are determined using WASP-IV package for the year 2015. This paper is organized as follows: Chapter 2 describes the overview of Tamil Nadu power sector. Chapter 3 discusses the implementation in WASP-IV. Chapter 4 deals with results and discussion, and Chapter 5 sums up with conclusion.

2. Tamil Nadu Power Sector-Ata Glance

Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) is an electrical power generation and distribution public-sector-undertaking, owned by the Government of Tamil Nadu. To meet and fulfill the energy needs of the State, TANGEDCO had a total installed capacity of 23754MW (at the end of November 2015) which[9] included shares from the State government, Central government and Independent Power Producers (IPP). Currently TANGEDCO operates four large thermal power stations in Tamil Nadu with the cumulative power generation of 4770 MW. The numerical distribution of this power generation is: Ennore Thermal Power Station (ETPS)- 450 MW, Mettur Thermal Power Station (MTPS)- 1,440 MW, North Chennai Thermal Power Station (NCTPS)- 1,830 MW, Tuticorin Thermal Power Station (TTPS)- 1,050 MW. As on 2015, TANGEDCO had 42 numbers of hydro plants, with a total capacity of 2190 MW. In addition, TANGEDCO had four Gas turbine plants with the total capacity of 524 MW. Due to economic constraints, the Gas turbines plants are operated only during peak hours. The share from central government was around 4155 MW which included coal and nuclear plants. The private power sectors also operated the thermal plants with 2665 MW capacity (Gas 503 MW, Diesel 412 MW and Coal 1750 MW).

The State of Tamil Nadu receives two monsoon seasons: The South-West monsoon from June to September and the North-East monsoon from October to December. This distinctive feature enables the state to be a favored wind power destination because the monsoon winds contribute to the bulk volume of the annual wind power generation. Nearly 98% of wind power is generated by private power sectors. Table 1 shows the various plants available in Tamil Nadu and their unit base, total capacity and plant capacity for the year 2015, assumed values of Forced Outage Rate (FOR) and maintenance schedules. FOR values are assumed as per their commencement period of the plants for Case 1. For Case 2, FOR values are assumed from their approximate plant availability[10], where the unavailability are considered to be a FOR. WECS has the highest assumed FOR, because of its intermittent in nature.

For the past five years, Tamil Nadu has been facing massive power deficit resulting with huge power cuts. This power shortage affects all the sectors leading to loss in production and subsequent loss of income. In order to manage the power cuts, most of the domestic consumers are using the Uninterrupted Power Supply (UPS) system and commercial consumers are using mini Diesel/Kerosene generators and industrial consumers are using large diesel generator. Figure 1 shows the various energy consuming sectors in Tamil Nadu[11]. Agricultural and commercial sectors consume 50% of total energy generated while 40% of energy is consumed by domestic and

Table 1. Tamil Nadu installed capacity for the year 2015

Sl. No.	Name of the plant	Type of fuel	No. of Units	Unit Base MW	Capacity Total MW	Plant Capacity (MW) 2015	FOR (%) Case 1	FOR(%) Case 2
1	ETPS	Coal	3	130	150	450	40	68
2	TTPS	Coal	5	200	210	1050	23	10
3	MTPS (Stage I&II)	Coal	4	200	210	840	23	13
4	MTPS (Stage III)	Coal	1	550	600	600	23	31
5	NCTPS (Stage I)	Coal	3	200	210	630	23	20
6	NCTPS (Stage II)	Coal	2	550	600	1200	23	13
7	Hydro	-	42	-	-	2191	-	-
8	TANGEDCO	Gas	5	75	104.8	524	47.6	47.6
9	Share from Central-I	Lignite	1	3300	4155	4155	15	25
10	Share from Central-II	Nuclear	1	450	987	987	15	30
11	IPP-I	Gas	10	45	50.3	503	38.5	48.5
12	IPP-II	Diesel	20	15	20.6	412	38.5	48.5
13	IPP-III	Coal	1	1050	1750	1750	38.5	33
14	Wind farm	-	1	10	7394	7394	81.4	81.4
15	Other RES (Bio mass & Bio gas)	-	1	10	1076	1076	75	75
	Total					23762		

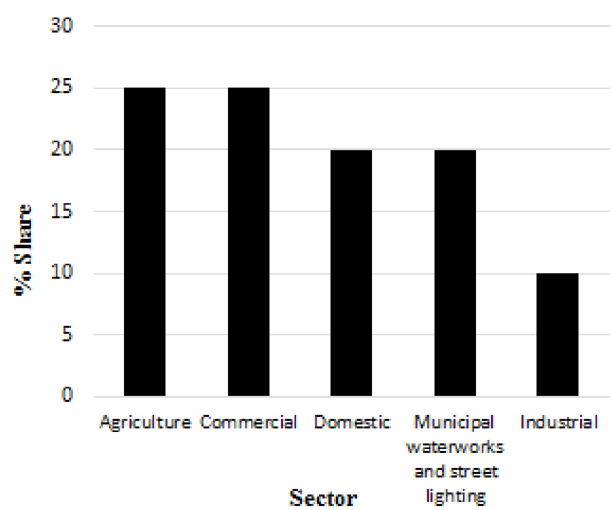

Figure 1. Sector wise electricity consumption.

municipal waterworks and street lighting sectors. The industrial sectors consume 10% of energy.

As on 31.11.2015, out of 23,762 MW installed capacities, coal plants shared 27.4%, gas plants shared 4.3%, nuclear plants and diesel plants shared 4.2% and 1.73%, Lignite plant shared 17.49%, each thereby making a cumulative contribution to 55.12% and renewable powers contributing to 44.87% (Wind 69.36%, and Hydro 20.55% and others including biomass, bio co-generation, solar and waste to energy 10.09%). The generation mix in the year 2015 is shown in Figure 2. Another major drawback in power generation faced by Tamil Nadu is the administrative and maintenance lapses. Many of the power generation units are working less than their rated capacity due to aging, i.e., many units have already crossed their efficient/economic lifetime. Five units in Ennore, one unit in Tuticorin were installed during 1970s; two units in Tuticorin, three units in Mettur were installed during 1980s; eight units in Neyveli (with the central share of 500 MW) were installed during 1960s and one unit in Neyveli thermal plant was installed in 1970s. Most of the hydro plants were installed between the years 1930s and 1970s. In addition, the Government of Tamil Nadu has decided to shut-off ETPS in the year 2017 due to poor plant load factor.

3. Implementation in WASP-IV

WASP-1V is one of the popular application software packages used for Generation Expansion Planning studies. In this study, WASP-IV[12] is used to analyze the reliability of the Tamil Nadu power generation in terms of LOLP and ENS for the year 2015. WASP-IV has been prepared by IAEA (International Atomic Energy Agency) and consists of seven modules viz LOADSY, FIXSYS, VARSYS, CONGEN, MERSIM, DYNPRO and REPROBAT. In order to carry out the reliability analysis, restricted peak demand data is collected from Southern Region Power Committee (SRPC). Both demand data and plant data are given as input to WASP-IV modules. The fifth order polynomial equation coefficient, which describes the Load Duration Curve (LDC), is given as input to LOADSY. Characteristics of all the candidate plants are given to FIXSYS. Then, month-wise energy generation from the plants is obtained from FIXSYS module and reliability indices LOLP and ENS are calculated. Figure 3 shows the flow chart for the study in WASP-IV. Characteristics like fuel type, number of units, minimum annual operating level in MW, maximum annual generating capacity in MW, heat rate at minimum operating level (kcal/kWh), average incremental heat rate (kcal/kWh), Forced Outage Rate (FOR) in %, scheduled maintenance in days per year, maintenance class size in MW etc., of all the plants in Tamil Nadu including share from central government are given as input to FIXSYS module of WASP-IV. Further, month-wise energy generations from the plants are obtained.

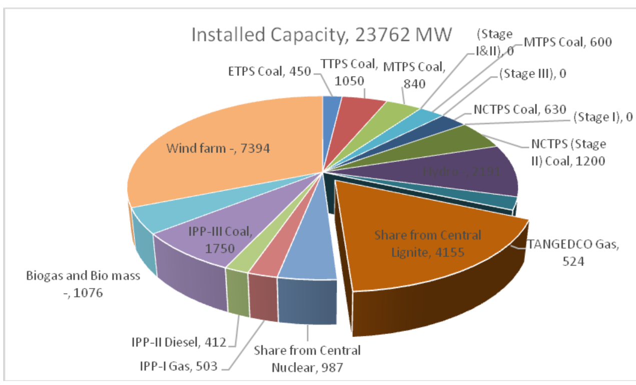

Figure 2. Generation mix in the year 2015.

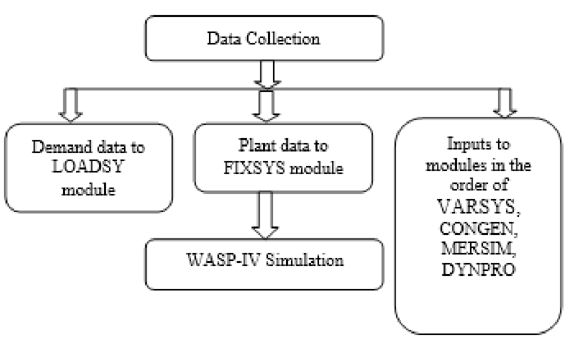

Figure 3. Flow chart for the study in WASP-IV.

3.1 Load Data

The daily load data of Tamil Nadu for the year 2015 is collected from SRPC. In this analysis, one month is counted as one season; accordingly 12 months are counted as 12 separate seasons/period. The daily Load Duration Curve for restricted demand is drawn with actual demand and assumed 5% reduction in actual restricted demand of the year 2015 is shown in Figure 4. This assumption is made for improving the reliability in demand side. Peak Demand Ratio (PDR) for each season is the ratio of each seasonal peak demand to peak demand of that year is also calculated and given in Table 2.

3.2 Assumptions Made

- FOR values and maintenance periods of generators are assumed as per the data given in Table 1. Capacity factor of each wind farm is assumed as 18.6 % as per the reference[13].
- Share from central sector is considered as lignite plant of 4155 MW capacity and nuclear plants (Kalpakkam and Koodankulam) and accounted separately.

3.3 Wind Plant Modelling in WASP-IV

There are several ways to model a wind plant in WASP IV and all have some kinds of approximation[14].

- Wind plant is modeled as negative load. The expected energy produced by WECS can be subtracted

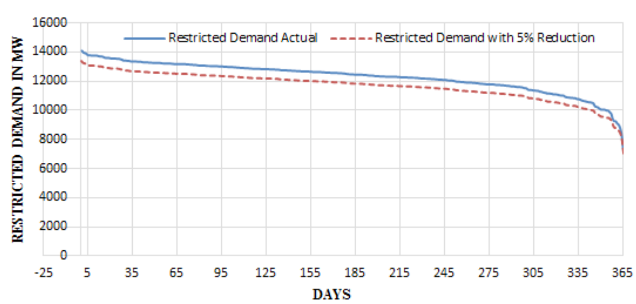

Figure 4. Load duration curve for restricted peak demand 2015

source: SRPC progress report 2015.

Table 2. Peak demand ratio in the year 2015

Month	1	2	3	4	5	6	7	8	9	10	11	12
PDR	0.8825	0.9184	0.9481	0.9245	0.9471	0.9646	1.0000	0.9923	0.9991	0.9667	0.9067	0.9211

from original load curve first before making LDC. Optimization is then done without considering wind turbines and the cost of wind turbine can then be added in the optimal case. Wind plant is modeled as a hydro plant with a base load capacity and inflow energy as a constraint.

- Wind plant is modeled as a thermal plant with increased FOR to reflect the variability of wind.

In this paper, wind plant is modeled as a thermal plant with high FOR (81.4%). FOR value of WECS is calculated using Sliding Window Technique[15]. According to this technique, FOR = (1 – Capacity Factor) and this model is taken into account for any wind power variation while calculating system reliability. Generating expansion evaluation with the help of WASP-IV program and DE algorithm for Iranian power grid with and without pumped storage power plants within 10 years were studied and compared[16].

4. Results and Discussions

In this section, simulation results for (i) restricted demands for Case 1 and for Case 2 with some of the measures to improve the reliability through its indices, are discussed.

4.1 Simulations Results for Restricted Demand – Case 1

Table 3 shows the month-wise energy generation from the plants in the year 2015 for Case 1. The total energy generation from all the plants was found to be 94850.4 GWh. The minimum and maximum energy generation occurred in the month of August and December respectively. As such, the energy generation patterns are as follows: Hydro plants had6400 GWh, Wind farms had 12044.9 GWh, Other RES had 1311.6 GWh and total renewable sources generation was 19756.5GWh. Table 4 gives the WASP – IV simulation results for restricted demand contains the minimum demand, peak demand, load factor and energy demand for every month of the year 2015. From the analysis, it is found that the minimum load factor was 86.32% against the minimum energy requirement of 7493.6 GWh which occurred in the month of November 2015. The maximum load factor was 95.59% which occurred in the month of February 2015 against the maximum energy requirement of 11346.2 GWh which occurred in the month of July 2015. Further, the value of LOLP was minimum in November and maximum in July and the value of ENS was minimum in November and maximum in July. In order to improve the reliability of the Tamil Nadu power grid for the considered cases, the following measures could be carried out in the demand/load side, energy conservation and in addition, energy intensity measures should be considered.

- For irrigation purposes ground water is the most possible source in Tamil Nadu, which leads to an increase in electricity demand. Efforts must be made to reduce the demand by concentrating on devising developmental strategies for efficient water management.
- LED lighting/energy efficient lighting system and Compact Fluorescent Lamps (CFLs)/LEDs may be utilized in the place of conventional lighting systems.
- Detailed energy audit may be conducted in domestic sector, commercial areas, offices, lighting, households etc., and necessary conservative measures could be recommended.
- Green tree plantation should be implemented throughout the state as it conserves energy, saves water, provides oxygen and helps in reduction of GHG. This will also lead to micro climate region, which reduces the temperature.

Due to the implementation of efficient energy utilization schemes, the load demand may reduce to 5% from the actual load requirement. Hence, the LDC becomes reduced and is given in Figure 4. Then, the WASP-IV simulations were made for 5% reduction in demand for Demand Side Management (DSM). As per the data available from the Table 5 the comparison of LOLP and ENS obtained from both Case 1 and Case 1- DSM, it is evident that LOLP and ENS for Case 1 is improved in each month when demand side load is reduced by 5% and the same is graphically shown in Figure 5 and Figure 6.

Table 3. Peak Month-wise energy generation from the plants- Case 1

Name of the plant	Periods												Total (GWh)
	1	2	3	4	5	6	7	8	9	10	11	12	
Hydro 1	100	100	100	100	75	75	150	350	350	350	350	100	2200
Hydro 2	250	250	250	250	100	100	200	650	650	650	650	200	4200
ETPS	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	197.1	191.2	196.3	2358.5
TTPS	589.6	590.2	590.2	589.3	589.6	590.2	590.2	590	590.2	589.4	557.1	580.8	7036.9
MTPS (Stage I&II)	472.2	472.2	472.2	472.2	472.2	472.2	472.2	472.2	472.2	472.2	462.9	472	5656.5
MTPS (Stage III)	323.8	337	337.1	323.6	328.4	336.9	337.2	331.6	329	327.1	289.6	317.3	3918.7
NCTPS (Stage I)	354.1	354.1	354.1	354.1	354.1	354.1	354.1	354.1	354.1	354.1	350.1	354.1	4245.5
NCTPS (StageI I)	600.7	650.4	660.9	618.6	631.5	662.5	669.5	633.1	626.9	617.5	556.7	609.2	7537.5
TANGEDCO	198.9	200.4	200.4	198.2	199.1	200.4	200.4	199.8	200.3	199.1	181	194.2	2372.5
Share from Central(Coal) - I	2108.6	2131.1	2159.1	2124.1	2146.2	2189.4	2214.8	2130.8	2135.5	2117.2	2013	2120.9	25590.7
Share from Central (Nuc.)-II	496.4	502.7	505.6	496.6	502.1	508.6	510.1	498.9	501	494.3	365.4	473.9	5855.6
IPP-I	222.1	225.8	225.9	221.1	222.9	225.9	225.8	224.2	224.8	223.2	200	216.6	2658.3
IPP-II	93.7	120.4	129.8	103.1	114.6	135.7	141.1	105.1	104.2	95	49.2	95.3	1287.2
IPP-III	527.5	621.7	630.4	538.1	577.3	635.7	640.9	565.4	549.9	526.9	268.5	493.6	6576
Wind farm	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004	1001.3	1004	12044.9
Other RES (Bio gas& Bio mass)	93.2	121.5	133.9	104.2	117.5	142.1	148.7	105.9	105.5	94.8	48.2	96.3	1311.6
Total	7631.9	7878.6	7950.7	7694.3	7631.6	7829.8	8056.1	8412.2	8394.7	8311.9	7534.2	7524.5	94850.4

Table 4. Simulation results for restricted demand- Case 1

Month	Min. demand (MW)	Max. demand (MW)	Load Factor (%)	Energy Demand (GWh)	Gen. (GWh)	ENS (GWh)	LOLP (%)
Jan.	9882.0	12149.0	93.72	8312.0	7632.0	679.8	48.21
Feb.	11346.2	12642.0	95.59	8821.6	7878.6	942.9	62.32
Mar.	11256.5	13051.0	95.02	9052.6	7950.6	1101.6	67.79
Apr.	9903.6	12727.0	91.43	8494.2	7694.2	799.9	53.38
May	9654.9	13038.0	90.27	8591.8	7631.6	959.8	59.76
Jun.	10854.8	13278.6	93.92	9103.3	7829.6	1273.3	71.46
Jul.	11729.3	13766.0	94.03	9449.2	8056.2	1393.0	74.63
Aug.	10718.8	13658.0	92.43	9215.6	8412.0	803.3	54.34
Sep.	11153.1	13754.0	91.66	9203.2	8394.8	807.6	53.95
Oct.	10326.2	13307.0	92.77	9011.5	8311.8	698.8	48.94
Nov.	7493.6	12481.0	86.32	7864.3	7534.2	319.5	25.18
Dec.	8818.8	12679.9	89.29	8264.6	7524.6	739.5	49.38

Table 5. Comparison of LOLP and ENS obtained from Case 1 and Case 1-DSM

Month	LOLP obtained fromCase 1(in %)	LOLP obtained from Case 1 - DSM (in %)	ENS obtained from Case 1(in GWh)	ENS obtained from Case 1 – DSM(in GWh)
Jan.	48.21	36.09	679.8	483.6
Feb.	62.32	50.19	942.9	708.6
Mar.	67.79	51.19	1101.6	733.5
Apr.	53.38	38.67	799.9	528.5
May	59.76	50.04	959.8	721.9
Jun.	71.46	54.67	1273.3	803.7
Jul.	74.63	66.16	1393.0	1066.5
Aug.	54.34	40.75	803.3	556.6
Sep.	53.95	46.45	807.6	651.9
Oct.	48.94	36.84	698.8	496.4
Nov.	25.18	18.80	319.5	213.8
Dec.	49.38	39.50	739.5	550.0
Total	669.34	529.35	10519	7515

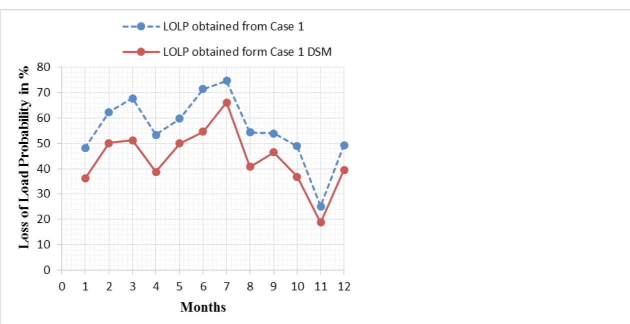

Figure 5. Comparison of LOLP obtained from both Case 1 and Case 1-DSM.

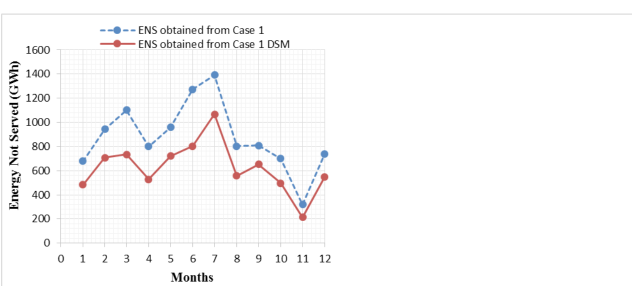

Figure 6. Comparison of ENS obtained from both Case 1 and Case 1-DSM.

4.2 Simulations Results for Restricted Demand – Case 2

Table 6 shows the month-wise energy generation from the plants in the year 2015 for Case 2. The total energy generation from all plants was 92428 GWh. Minimum and maximum energy generations occured in the month of December and August respectively. The energy generation patterns are as follows: Hydro plants had 6400 GWh, Wind farms had 12044.9 GWh, other RES had 1353.9 GWh and total renewable sources generation was 19598.8 GWh. Table 7 shows simulation results for restricted demand for Case 2.

Here also it is presumed that the implementation of efficient energy utilization schemes and the load demand may reduce to 5% from the actual load requirement thereby reducing the LDC. Then the WASP-IV simulations are made for 5% reduction in demand for Demand Side Management (DSM). Table 8 gives the comparison of LOLP and as per the ENS obtained from both Case 2 and Case 2- DSM, it can be evident that LOLP and ENS for Case 2 are improved in each month when demand side load is reduced by 5% as illustrated clearly in Figure 7 and Figure 8.

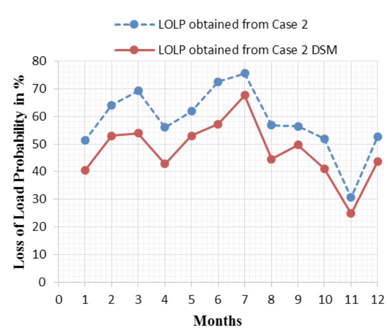

Figure 7. Comparison of LOLP obtained from both Case 2 and Case 2-DSM.

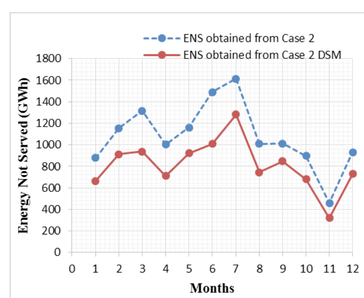

Figure 8. Comparison of ENDS obtained from both Case 2 and Case 2-DSM.

Table 6. Month–wise energy generation from the plants- Case 2

Name of the plant	Periods												Total (GWh)
	1	2	3	4	5	6	7	8	9	10	11	12	
Hydro 1	100	100	100	100	75	75	150	350	350	350	350	100	2200
Hydro 2	250	250	250	250	100	100	200	650	650	650	650	200	4200
ETPS	105.1	105.1	105.1	105.1	105.1	105.1	105.1	105.1	105.1	105.1	101.8	104.6	1257.6
TTPS	689.1	689.8	689.9	688.6	689.1	689.8	689.8	689.6	689.9	688.8	649.4	678.4	8222.2
MTPS (Stage I&II)	533.5	533.5	533.5	533.5	533.5	533.5	533.5	533.5	533.5	533.5	522.5	533.2	6390.5
MTPS (Stage III)	289.2	302	302	289.2	293.8	301.8	302.2	296.8	294	292.4	258.4	283.6	3505.4
NCTPS (Stage I)	367.9	367.9	367.9	367.9	367.9	367.9	367.9	367.9	367.9	367.9	363.8	367.9	4410.9
NCTPS (StageI I)	674.9	732.1	745.5	696	711.5	747.6	756	712.8	706.2	694.6	627.7	686.6	8491.4
TANGEDCO	198.5	200.4	200.4	197.6	198.7	200.5	200.4	199.6	200.3	198.8	179.6	193.5	2368.4
Share from Central(Coal) - I	1856.9	1870.8	1893.8	1868.2	1885.8	1920	1942	1872.8	1877.5	1862.2	1766.4	1865.1	22481.5
Share from Central (Nuc.)- II	408.6	414.7	418.6	409.4	415.3	423	425.5	411.2	413.4	406.8	303.6	390.1	4840.1
IPP-I	185.5	189.1	189.1	184.5	186.3	189.2	189.1	187.5	188.1	186.6	166.3	180.8	2222.3
IPP-II	82.1	102.6	110.1	89.6	98.4	114.8	119.1	90.9	90.4	83.2	49.1	84	1114.2
IPP-III	589.7	680.1	689.5	600.8	638.9	696.3	702.1	626.1	612	589.4	341.6	558.2	7324.7
Wind farm	1004	1004	1004	1004	1004	1004	1004	1004	1004	1004	1001.3	1004	12044.9
Other RES (Bio gas & Bio mass)	97.7	123.5	135.2	107.9	120.3	143.3	149.5	109.3	108.8	99.2	58.2	101.3	1353.9
Total	7432.7	7665.6	7734.6	7492.3	7423.6	7611.8	7836.2	8207.1	8191.1	8112.5	7389.7	7331.3	92428

Table 7. Simulation results for restricted demand- Case 2

Month	Min. demand (MW)	Max. demand (MW)	Load Factor (%)	Energy Demand (GWh)	Gen. (GWh)	ENS (GWh)	LOLP (%)
Jan.	9882.0	12149.0	93.72	8312.0	7432.6	879.2	51.22
Feb.	11346.2	12642.0	95.58	8821.6	7665.7	1155.8	64.10
Mar.	11256.5	13051.0	94.99	9052.6	7734.6	1317.5	69.20
Apr.	9903.6	12727.0	91.41	8494.2	7492.3	1001.9	56.04
May	9654.9	13038.0	90.23	8591.8	7423.5	1161.9	61.87
Jun.	10854.8	13278.6	93.88	9103.3	7611.7	1491.2	72.60
Jul.	11729.3	13766.0	94.01	9449.2	7836.3	1612.9	75.56
Aug.	10718.8	13658.0	92.42	9215.6	8207.1	1008.3	56.85
Sep.	11153.1	13754.0	91.62	9203.2	8191.0	1011.3	56.49
Oct.	10326.2	13307.0	92.73	9011.5	8112.5	897.9	51.92
Nov.	7493.6	12481.0	86.27	7864.3	7389.5	458.7	30.62
Dec.	8818.8	12679.9	89.25	8264.6	7331.1	932.9	52.56

Table 8. Comparison of LOLP and ENS obtained from Case 2 and Case 2-DSM

Month	LOLP obtained from Case 2 (%)	LOLP obtained from Case 2 - DSM (%)	ENS obtained from Case 2 (in GWh)	ENS obtained from Case 2 - DSM (in GWh)
Jan.	51.22	40.40	879.2	664.7
Feb.	64.10	52.98	1155.8	911.5
Mar.	69.20	53.92	1317.5	936.2
Apr.	56.04	42.75	1001.9	712.8
May	61.87	52.94	1161.9	922.0
Jun.	72.60	57.16	1491.2	1009.9
Jul.	75.56	67.69	1612.9	1281.2
Aug.	56.85	44.50	1008.3	745.8
Sep.	56.49	49.66	1011.3	848.8
Oct.	51.92	41.05	897.9	679.0
Nov.	30.62	24.87	458.7	321.6
Dec.	52.56	43.60	932.9	729.2
Total	699.03	571.52	12929.5	9762.7

The following observations could be made from the simulation results obtained using WASP-IV. There may be some deviations in LOLP and ENS values in the month-wise report. However, when it is compared for the whole year, it is very less, due to the following reasons:

- Actual value of FOR (unavailability) of all plants is not available and practically it is varying.
- FOR value for WECS is considered as the fixed one for all periods/seasons. However, the availability of wind power is intermittent one.
- Availability of hydropower is also seasonal.
- Import of power from other state is not considered in this analysis.
- Some of the plants (new plant/old plant) may operate with derated capacities. However, it is not considered in this analysis.

5. Conclusion

In this paper, reliability is analyzed through its indices of LOLP and ENS for Tamil Nadu power grid for the year 2015. The reliability is evaluated for cases with varying Forced Outage Rate of the plant. In Case 1, FOR is assumed as per the commencement period. In Case 2 FOR values are assumed from their approximate plant availability which are taken from SRPC, where the unavailability is considered to be a Forced Outage Rate. Reliability indices LOLP and ENS are calculated using WASP-IV. In order to improve the reliability it should be considered to have the implementation of efficient energy utilization schemes by reducing the load demand by 5% from the actual load requirement. It is observed that LOLP for the year improved from 669.34% to 529.35% and that of ENS improved from10519Gwh to 7515Gwhfor Case1. Similarly, the total LOLP for the year improved from 669.03% to 571.35% and that of ENS improved from12929.5 Gwh to 9762.7 Gwh for Case 2. The various results obtained using WASP-IV is closer to each other and can be used as a base for GEP. Some of the points to be put forth to overcome the power deficit are also proposed.

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