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ABSTRACT

The reliability of Tamil Nadu power grid is analyzed for the year 2014. In a power system, to ensure that, whether the total installed capacity is sufficient to meet the demand is identified by system reliability. Reliability indices are used as deciding criteria on new investments in generation capacities. Tamil Nadu has the highest renewable power penetration of 49% of the total installed capacity at the end of the year 2014. The reliability index, Energy Not Served (ENS) for every month of the year 2014 has been analyzed using Wien Automatic System Planning -IV (WASP-IV) package for both restricted and un-restricted peak demand of Tamil Nadu.

Keywords: *Energy not served, Reliability, Tamil Nadu, WASP-IV*

1.INTRODUCTION

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 of a device or system performing its function adequately, for the period of time intended, under the specified operating conditions [2]. The reliability of power supply is, related to the probability of providing customers with continuous service and with a voltage and frequency within prescribed ranges around the nominal values. Power systems reliability considers the performance of the system as a whole, considering generation facilities as well as the transmission network and the distribution grid. In this paper, only the reliability of generation capacity is analyzed. Providing additional generation capacity increases the reliability of power supply and adds value to the service, but it also costs money. A modern power system is complex, highly integrated and very large. Fortunately, the system can be divided into appropriate subsystems like generation, transmission and distribution. Reliability studies are carried out individually and in combinations of the three areas. The evaluation of transmission and distribution reliability is beyond the scope of this work. The actual degree of reliability experienced by a customer will vary from region to region. Different functional areas may offer different degrees of reliability.

It is reported that southern region of India had the highest peak demand shortage of 14.5 MW and energy shortages of 10.5 MU for the financial year 2010-2011. [3]. Reliability indices, Loss of Load Probability (LOLP) and Energy Not Served (ENS) for Tamil Nadu, for the year 2012 were calculated using WASP-IV [4]. Tamil Nadu had the minimum peak shortage of 1.4% in August and September 2013 and maximum peak demand shortage of 17.9% in January 2013 and the minimum energy shortage of 1.5% in October 2013 and maximum energy shortage of 21.7% in January 2013 [5]. The average peak demand and energy shortage of the year 2013 had been calculated as 8.19% and 10.5% respectively. A climate - aware generation planning has been proposed for Tamil Nadu [6]. The performance of various plants in Tamil Nadu was analyzed for the period 2004-2008 [7]. Tamil Nadu is the leading Indian state in grid-connected renewable, especially wind energy.. At the end of 2014 Tamil Nadu had 7206 MW installed wind power generation capacity [8]. In Tamil Nadu, two kinds of load demands are considered restricted demand and un-restricted demand. In this paper both demands are taken into account by considered two cases. In this paper, WASP-IV package has been used to analyse the reliability in terms of Energy Not Served (ENS) for Tamil Nadu for the year 2014. The rest of this paper is organized as follows: Chapter 2 describes overview of power sector in Tamil Nadu. Chapter 3 provides the implementation in WASP-IV. Chapter 4 provides results and discussion and Chapter 5 concludes.

2. Tamil Nadu Power Sector-An Overview

Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO) is an electrical power generation and distribution public-sector-undertaking that is owned by the Government of Tamil Nadu .To satisfy the energy needs of the state, TANGEDCO has a total installed capacity of 21793 MW (at the end of December 2014) which includes shares from the State government, Central government and Independent Power Producers (IPP).The TANGEDCO operates four large thermal power stations (4770 MW):

i. Ennore Thermal Power Station (ETPS) - 450 MW (2×60, 3×110 MW)
ii. Mettur Thermal Power Station (MTPS) - 1440 MW (4×210, 1×600 MW)
iii. North Chennai Thermal Power Station (NCTPS) 1830 MW (3×210, 2×600 MW)
iv. Tuticorin Thermal Power Station (TTPS) - 1050 MW (5×210 MW)

TANGEDCO has 42 numbers of hydro plants, with a total capacity of 2190 MW. TANGEDCO also has four gas turbine plants and its total capacity is 515 MW. Due to economic consideration these plants are operated only during peak hours. The share from central government is around 4177 MW (December 2014) which includes coal and nuclear plants. The state of Tamil Nadu has two monsoon seasons: south-west monsoon from June to September and the north-east monsoon from October to December. This distinctive feature helps Tamil Nadu to become a favored wind power destination because the monsoon winds contribute to the bulk of the annual wind power generation. Nearly 98% of wind power is generated by private power sectors. The private power sectors also operate the thermal plants of capacity 2065 MW (Gas 503 MW, Diesel 412 MW and Coal 1150 MW). For the past five years, Tamil Nadu has been facing massive power deficits hence the state is now facing huge power cuts. This power shortage affects all the sectors leading to loss in production and 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 generators.

Table I shows the various energy consuming sectors in Tamil Nadu [9]. Agricultural and commercial sectors consume 50% of total energy generation, 40% of energy is consumed by domestic and municipal waterworks and street lighting sectors. The industrial sectors consume 10% of energy.

TABLE. I - SECTOR WISE ELECTRICITY CONSUMPTION [9]

Sl.No.	Sector	% share
1	Agriculture	25
2	Commercial	25
3	Domestic	20
4	Municipal waterworks and street lighting	20
5	Industrial	10

Table II shows technologies and the existing installed capacity of the state at the end of the year 2014 and the assumed values of Forced Outage Rate (FOR) and maintenance schedules. FOR values are assumed as per their commencement period, and WECS has highest assumed FOR, because of its intermittent in nature.

TABLE II- INSTALLED GENERATION CAPACIY IN TAMIL NADU 2014.

Sl. No.	Name of the plant	Type of fuel	Capacity (MW)	FOR (%)	Maintenance Schedule (Days/yr)
1	ETPS	Coal	450	40	50
2	TTPS	Coal	1050	33	30
3	MTPS (Stage I&II)	Coal	840	33	30
4	MTPS (Stage III)	Coal	600	33	30
5	NCTPS (Stage I)	Coal	630	33	30
6	NCTPS (Stage II)	Coal	1200	33	30
7	Hydro	-	2190	-	10
8	TANGEDCO	Gas	515	47.6	30
9	Share from Central	Lignite	3653	25	25
10	Share from Central	Nuclear	524	30	25
11	IPP-I	Gas	503	48.5	30
12	IPP-II	Diesel	412	48.5	25
13	IPP-III	Coal	1150	33	25
14	Biogas and Bio mass	-	870	75	30
15	Wind farm	-	7206	81.4	30
Total			21793	-	

As on 31.12.2014, out of 21,793MW installed capacities, coal plants share 44%, gas plants share 5%, nuclear plants and diesel plants share 2% each and therefore total thermal contribution was 53% and renewable powers contribution was 47% (Wind 33%, Biomass 4% and Hydro 10%). The generation mix in the year 2014 is shown in Fig. 1.

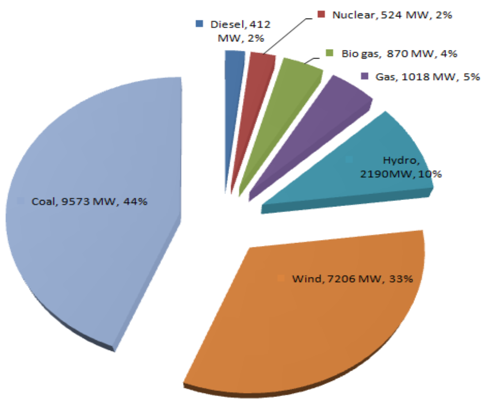

Fig. 1. Generation mix in the year 2014.

Many of the units are working less than their rated capacity due to aging, i.e., many units 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 (central share, 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. The Government of Tamil Nadu has decided to shut-off all 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 GEP studies. In this study, WASP-IV is used to analyze the reliability of the Tamil Nadu power generation in terms of ENS for the year 2014. In order to carry out the reliability analysis restricted peak demand and un-restricted peak demand data are collected from [10]. 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 are obtained from FIXSYS module and reliability index ENS is calculated. Fig.2. shows the flow for the study in WASP-IV.

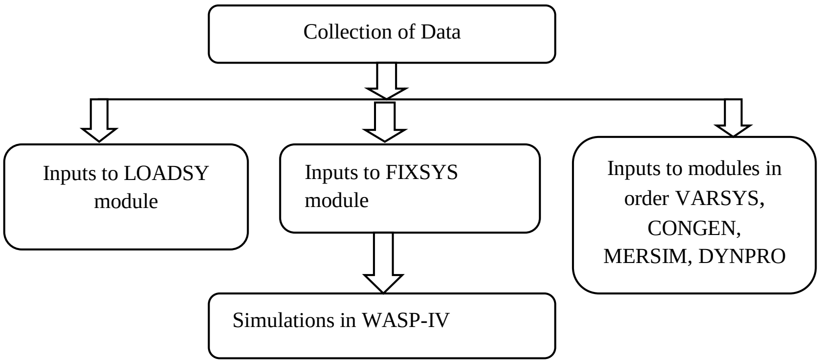

Fig. 2. Flow chart for the study in WASP-IV.

3.1 Load data

The daily load data of Tamil Nadu for the year 2014 is available in [10]. Each month is considered as a separate season / period. The LDC for restricted peak demand and un-restricted demand of the year 2014 is shown in Fig. 3. Peak Demand Ratio (PDR) for each season is the ratio of each seasonal peak demand divided by peak demand of that year.

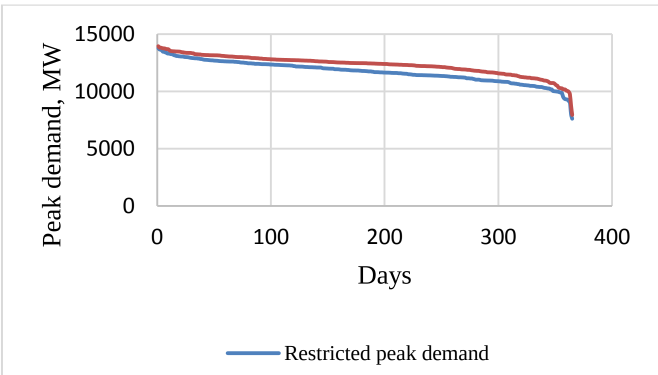

Fig. 3. Flow chart for the study in WASP-IV.

Table III shows the month-wise PDR of every month of year 2014 for both demands.

TABLE III - PEAK DEMAND RATIO IN THE YEAR 2014

Month	PDR (res)	PDR (un-res)
January	0.927	0.970
February	0.874	0.934
March	0.919	0.991
April	0.926	0.981
May	0.943	0.957
June	1	1
July	0.965	0.964
August	0.936	0.930
September	0.959	0.948
October	0.857	0.917
November	0.829	0.900
December	0.845	0.901

Fig.4 shows the PDR comparison for both restricted and un-restricted peak demand and it should be inferred that, the annual peak demand occurs in the month of June and minimum demand occurs in November for the both demands. Table IV shows the annual summary of load demand observed from LOASY module, of WASP-IV.

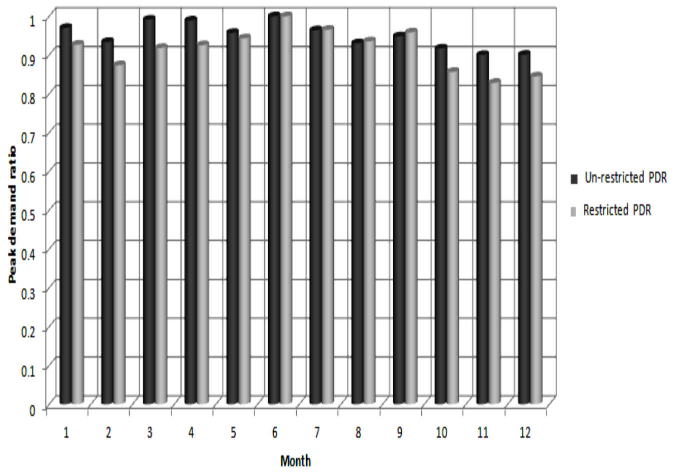

Fig. 4. Flow chart for the study in WASP-IV.

In the year 2014, for restricted load, minimum demand was 7674 MW, maximum demand was 13771 MW and energy required was 102658 GWh. The annual load factor is 85.10%. For un-restricted load, minimum demand was 8117 MW, maximum demand was 13936 MW and energy required was 108134 GWh. The annual load factor is 88.58%.

TABLE IV-ANNUAL SUMMARY OF DEMAND FOR THE YEAR 2014

Demand type	Minimum demand (MW)	Maximum demand (MW)	Energy demand (GWh)	Load Factor (%)
Restricted	7674.7	13771	102658.6	85.10
Un-restricted	8117.9	13936	108134.6	88.58

Characteristics like fuel type, number of units, minimum operating level (each year) in MW, maximum generating capacity (each year) 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 are given as input to FIXSYS module of WASP-IV. Month-wise energy generations from the plants are obtained.

Assumptions made

i) FOR values and maintenance periods of generators are assumed as per the data given in Table II.
ii) Share from central sector is considered as lignite plant of capacity 3653 MW and nuclear plants (Kalpakkam and Koodankulam) are considered separately.
iii) Capacity factor of each wind farm is assumed as 18.6 % [12].

iv) Biomass co-generation of 610 MW, biomass power of 161.15 MW, small hydro of 90.05 MW, solar of 10 MW and waste to energy of 4.25 MW are combined together and considered as biomass plant of capacity 870 MW.

Wind Plant modelling in WASP-IV

There are several ways to model a wind plant in WASP and all have some kinds of approximation [13].

i) Wind plant is modeled as negative load. The expected energy produced by WECS can be subtracted from original load curve first and then the LDC is made. Calculation made without considering WECS and then it could be added in optimal case. ii) Wind plant is modeled as a hydro plant with a base load capacity and inflow energy as a constraint. iii) Wind plant is modeled as a thermal plant with increased FOR to reflect the variability of wind. In this paper, a wind plant is modeled as a thermal plant with high FOR (81.4%). FOR value of WECS is calculated using Sliding Window Technique [14].

4. Results and Discussions

In this section, simulation results for (i) restricted and un-restricted peak demands and (ii) Some of the points to improve the Reliability of Tamil Nadu power generation are discussed.

Simulation results for restricted peak demand

Table V shows the month-wise energy generation from the plants in the year 2014. The total energy generation from all plants is 101544.8 GWh. The minimum and maximum energy generations occur in the month of October and July respectively.

The energy generation patterns are as follows: Hydro plants 6400 GWh (6.3%), Bio-mass 5543.2 GWh (5.46%), WECS 10762.7 GWh (10.6%) and total renewable sources is 22705.9 GWh (22.36%). Table VI & VII shows the minimum demand, peak demand, load factor and energy demand for the every month of year 2014 for restricted and un-restricted demands.

i) For restricted demands

The minimum load factor (88.98%) and minimum energy requirement (7665 GWh) occurs in the month of October 2014. The maximum load factor (96.39%) and maximum energy requirement (9469.7 GWh) occurs in the month of February 2014. The value of ENS is minimum in September and the maximum in February.

ii) For un-restricted demands

The minimum load factor (89.23%) and minimum energy requirement (8324.7 GWh) occur in the month of October 2014. The maximum load factor (96.21%) occurs in the month of February 2014 and maximum energy requirement (9.599 GWh) occurs in the month of April 2014.The value of ENS is minimum in January and maximum in February.

TABLE V.- MONTH-WISE ENERGY GENERATION FROM THE PLANTS

Name of the plant	**Periods**												**Total (GWh)**
	1	2	3	4	5	6	7	8	9	10	11	12	
ETPS	210.2	315.4	315.4	210.2	315.4	315.4	315.4	210.2	210.2	315.4	210.2	315.4	3258.8
TTPS	741.2	555.9	679.4	741.2	741.2	741.2	741.2	617.7	679.4	617.8	679.4	617.7	8153.4
MTPS (Stage I&II)	593	444.7	543.5	593	593	593	593	494.1	543.6	494.2	543.5	494.1	6522.7
MTPS (Stage III)	423.6	282.4	423.5	423.6	423.6	423.6	423.6	423.5	423.6	282.4	282.3	423.6	4659.4
NCTPS (Stage I)	444.7	333.5	407.7	444.7	444.7	444.7	444.7	370.6	407.7	370.7	407.7	370.6	4892
NCTPS (StageI I)	847.3	564.7	847.1	847	847.2	847.2	847.1	847.1	847.2	564.8	564.7	847.3	9318.8
Hydro	350	350	350	350	175	175	350	1000	1000	1000	1000	300	6400
TANGEDCO	197	157.6	157.6	197	197	197	197	157.6	197	157.6	197	157.6	2167.1
Share from Central(Coal)	2596	2600.2	2600.1	2600	2591.5	2600.4	2600.1	2599.1	2576.2	1932.3	1559.5	2080	28935.4
Share from Central (Nuc.)	355	371.1	370.9	369.9	346.2	371	370.5	356.5	298.9	286.8	61.6	370.6	3928.9
IPP-I	170.3	151.5	170.3	170.3	170.3	189.1	170.3	170.3	188	189.1	170.3	170.3	2080.3
IPP-II	12.7	59.1	14.7	11.7	16.2	72.5	40	13.8	8	27.9	47.8	46.9	371.3
IPP-III	255.6	673.9	306.5	271.8	281.4	611.8	531.8	204.3	187.6	230.8	619.5	375.8	4550.8
Biogas and Bio mass	470	587.4	543.9	507.1	470.8	578.4	569	431	364.1	250.7	390.6	380.2	5543.2
Wind farm	870.9	889.6	870.9	870.9	929.6	978.4	958.9	880.7	861.1	880.7	880.7	890.4	10762.7
Total	8537.5	8337	8601.5	8608.4	8543.1	9138.7	9152.6	8776.5	8792.6	7601.2	7614.8	7840.5	101544.8

TABLE VI- SIMULATION RESULTS FOR RESTRICTED DEMAND LOADS

Month	Min. demand (MW)	Peak demand (MW)	Load Factor (%)	Energy Demand (GWh)	Gen. (GWh)	ENS (GWh)
Jan.	9844.9	12764	92.22	8592.4	8537.5	54.9
Feb.	11000.6	12037	96.39	9469.7	9337	132.7
Mar.	11281.3	12650	93.84	8665.6	8601.5	64.1
Apr.	11032.5	12747	93.12	8664.9	8608.4	56.5
May	9797.8	12991	90.74	8605.5	8543.1	62.4
Jun.	11370.7	13771	93.09	9358.1	9138.7	219.4
Jul.	11239.2	13293	95.45	9262	9152.6	109.4
Aug.	10864.8	12884	93.98	8839	8776.5	62.5
Sep.	10222.1	13200	91.71	8837.5	8792.6	44.9
Oct.	7674.7	11800	88.98	7665	7601.2	63.8
Nov.	9378.7	11411	92.75	7726.3	7614.8	111.5
Dec.	9919.1	11638	93.55	7947.6	7840.5	107.1

TABLE VII-SIMULATION RESULTS FOR UNRESTRICTED DEMAND LOADS

Month	Min. demand (MW)	Peak demand (MW)	Load Factor (%)	Energy Demand (GWh)	Gen. (GWh)	ENS (GWh)
Jan.	10217.1	13520	90.08	8890.9	8537.5	353.4
Feb.	11344.3	13014	96.21	9640	9337	303
Mar.	11332.7	13817	92.40	9319.7	8601.5	718.2
Apr.	11848.2	13785	95.39	9599	8608.4	990.6
May	10514.1	13339	92.55	9011.6	8543.1	468.5
Jun.	12125.7	13936	93.39	9500.5	9138.7	361.8
Jul.	11237	13434	94.84	9300.3	9152.6	147.7
Aug.	11488.8	12967	93	8803.2	8776.5	26.7
Sep.	10734.8	13217	94.8	9147.1	8792.6	354.5
Oct.	8117.9	12780	89.23	8324.7	7601.2	723.5
Nov.	9983.6	12549	91.91	8419.6	7614.8	804.8
Dec.	10204.3	12556	93.58	8577.6	7840.5	737.1
Total	-	-	-	108534.2	102544.4	5989.8

The following observations should be made from the simulation results obtained using WASP-IV. There may be more deviations in ENS values in the month-wise report. However, when it is compared for the whole year, it is very less. It may be 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.

Annual energy generated from plants is based on the assumption of FOR values and maintenance periods given in Table II.
There are some deviations occurred in the ENS result for both restricted and un-restricted loads conditions may be due to assumptions made in this study. If un-restricted peak demand is considered, the total ENS in the year will be 2552.6 GWh. But by considering restricted peak demand the total ENS in the year will be 2089.2 GWh, this value may be useful for further planning studies. The planning study may be carried out to improve the reliability and meet the demand in future.

The reliability of Tamil Nadu power generation is poor due to more energy shortage. One way of reducing the power deficit of Tamil Nadu is to add more conventional plants, which results in reduction of emission of Green House Gases (GHG), but requires huge investments. Other ways are demand side management and maximum utilization of renewable resources.

Points may be incorporated to improve the Reliability of Tamil Nadu power grid

Supply/generation side demand which incorporates Integrated Resource Planning (IRP), may give no of benefits to consumer [15]. In the supply side, incorporation of renewable energy sources such as solar, wind, bio-mass must be encouraged. Tamil Nadu has nearly 300 sunny days; hence utilizing the available resource is more economic. Solar energy may be suggested for educational institutes, agriculture, domestic for lighting and cooking etc.,
Approximately 1,27,000 MW (at 80 m) of off-shore wind potential is available in Tamil Nadu. Also it has a plant load factor of 35% and above. By incorporating these resources, more electricity can be generated to meet day-by-day increasing load demand. It also helps in creating green environment.

In the demand / load side, energy conservation and 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 development of strategies for efficient water management. LED lighting/energy efficient lighting system and Compact Fluorescent Lamps (CFLs)/LEDs may be preferred. Detailed energy audit may be conducted in domestic sector, commercial areas, offices, lighting, households etc. 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.

5. Conclusion

In this paper, reliability index Energy Not Served is calculated for Tamil Nadu power grid for the year 2014. The reliability is evaluated in terms of ENS for both restricted and un-restricted demands using WASP-IV software package. There are more deviations in ENS values in the month-wise report. However, when it is compared for the whole year, it is very less. In this paper, each month is considered as a separate season. The various results obtained using WASP-IV is closer to each other (restricted demand and un-restricted demand) and it can be used as a base for GEP. Some of the points to be put forth, to overcome the power deficit are also discussed. Integrated Energy Policy Development for Tamil Nadu will be under taken as future work.

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APPENDIX

A.1.TAMIL NADU HYDRO-ELECTRIC GENERATING CIRCLES

In Tamil Nadu, there are four hydro-electric generating circles namely,

I) Kundah hydro-electric generating circles has 12 hydro stations II) Kadamparai hydro-electric generating circles has 9 hydro stations III) Erode hydro-electric generating circles has 11 hydro stations IV)Tirunelveli hydro-electric generating circles has 10 hydro stations.

Sl.No,	Kundah hydro-electric generating circles	Kadamparai hydro-electric generating circles	Erode hydro-electric generating circles	Tirunelveli hydro-electric generating
1	Kundah Power House-I	Sholayar power house – I	Mettur dam power house	Kodayar power house – I
2	Kundah Power House-II	Sholayar power house – II	Mettur tunnel power house	Kodayar power house – II
3	Kundah Power House-III	Aliyar power house	Lower mettur barrage power house -I / Chekkanur	Servalar power house
4	Kundah Power House-IV	Aliyar mini power house	Lower mettur barrage power house -II / Nerinjipettai	Papanasam power house
5	Kundah Power House-V	Sarkarpathy power house	Lower mettur barrage power house-III	Suruliyar power house
6	Kundah Power House-VI	Kadamparai power house (pumped storage scheme)	Lower mettur barrage power house -IV /Uratchikotta	Periyar power house
7	Pykara power house /Singara	Thirumurthy mini power house	Bhavani kattalai barrgae – I	Vaigai power house
8	Moyar power house	Poonachi mini power house	Sathanur	Perunchani
9	Maravakandy power house	Amaravathi	Lower bhavani -1/ Micro hydel power house/ Bhavani	Periyar vagai mini I
10	Mukurthy micro power house	-	Lower bhavani RBC	Periyar vagai mini II
11	Pykara (PUSHEP) Ultimate Stage Hydroelectric Power Plant	-	Bhavani kattalai barrgae – II.	-
12	Pykara micro power house	-	-	-

A.2. WASP_IV MODULES

WASP-IV has been prepared by IAEA (International Atomic Energy Agency) and consists of seven modules via LOADSY, FIXSYS, VARSYS, CONGEN, MERSIM, DYNPRO and REPROBAT [11]

Module 1: LOADSY (**Load Sy**stem Description), processes information describing period peak loads and load duration curves for the power system.

Module 2: FIXSYS (**Fix**ed **Sys**tem Description), processes information describing the existing generation system and all future additions or retirements, which are to be firmly scheduled.

Module 3: VARSYS (**Var**iable **Sys**tem Description), processes information describing the various generating plants which are to be considered as candidates for expanding the generation system.

Module 4: CONGEN (**Con**figuration **Gen**erator), used to calculate all possible year-to-year combinations of expansion candidate additions, which satisfy certain input constraints and which in combination with the fixed system can satisfy the loads. CONGEN also calculates the basic economic loading order of the combined list of FIXSYS and VARSYS plants.

Module 5: MERSIM (**Mer**ge and **Sim**ulate), considers all configurations put forward by CONGEN and uses probabilistic simulation of system operation to calculate the associated production costs, energy not served and system reliability for each configuration.

Module 6: DYNPRO (**Dyn**amic **Pr**ogramming **O**ptimization), determines the optimum expansion plan based on previously derived operating costs along with input information on capital costs, energy not served cost and economic parameters and reliability criteria.

Module 7: REPROBAT (**Rep**ort W**r**iter **o**f WASP in a **Bat**ched Environment), writes a report summarizing the total or partial results for the optimum or near optimum power system expansion plan and for fixed expansion schedules.