ANALYSIS OF PERFORMANCE FACTORS OF AN INDIAN POWER SYSTEM FOR DIFFERENT DEMAND GROWTH SCENARIOS

S. SARAVANAN[1] K. KARUNANITHI[*,2] M. RASUKUTTI[3]
[1]B V Raju Institute of Technology, Narsapur, Telangana, India, saravananklu@gmail.com
[*,2]Corresponding author, Siddharth Institute of Engg. and Tech., Andhra Pradesh, India, k.karunanithiklu@gmail.com
[3]Kalasalingam University, Tamil Nadu, India, veeramarch18@gmail.com

Abstract: *This paper presents solutions to Generation Expansion Planning (GEP) problem for an Indian state, Telangana power system. GEP is a highly constrained and non-linear optimization problem. In early days, the electricity generation was mostly from conventional types of plants and the GEP problems were solved with only conventional plants as expansion candidate plants which emit Green House Gases (GHG) and other pollutants lead to environmental pollution. Due to higher reduction rate of fossil fuels and pollution impacts, it is important to consider Renewable Energy Sources (RES) such as wind, solar, biomass etc., as alternatives for planning the future power system. In this research study, Long-range Energy Alternative Planning (LEAP) software has been used for solving the GEP problem for the state of Telangana for fifteen years from 2016 to 2030. The various scenarios are proposed such as Green House Gases Mitigation Scenario (GHGMS), Low Demand Growth Scenario (LDGS) and two different High Demand Growth Scenarios (HDGS1 and HDGS2) in addition to Reference Scenario (REFS). In all scenarios, the various system performance factors like installed capacity required, emission of pollutants, reliability and total cost are analyzed using LEAP.*

Key words: *Generation Expansion Planning, Green House Gases, Renewable Energy Sources, Telangana State*

1. Introduction and literature survey

Electricity is one of the imperative and decisive components for the sustained growth of economic and welfare of any nation. The Indian power sector is mainly administrated by the Central Electricity Authority (CEA) of India. The Indian power sector has three major sub-divisions which includes Generation, Transmission and Distribution. As far as the generation of electricity is concerned, it can be owned and operated by Central, State and Private sectors. The Indian power sector is one of the most diversified in the world. Generally around 70 of power is generated from the conventional sources such as fossil fuels, nuclear, oil, gas, hydro and remaining 30% of power is generated from the renewable energy sources like solar, wind, agriculture and industrial waste.

The demand of electricity in the country has increased drastically and is expected to increase future year also. In order to meet the requirement of the electricity demand, immense addition to the installed generation capacity is required. The main objective of any power system is to supply the electric energy economically and reliably to all kinds of consumers and also the main responsibility of power utilities is to recognize their customers' electricity demand in future and properly plan the additional capacity to be installed in order to supply the required power. Therefore Generation Expansion Planning (GEP) is a one of the utmost crucial problem for any nation for their economic development. Now a day RES play alternatives for fossil fuel based power plants due to its pollution impact. The coal based plants are the main contributor of CO_2 emissions. For last three decades, approximately 70% of the electric power is generated from fossil fuels and almost 40% of global CO_2 emissions derived from power generation. The CO_2 emission can be minimized by incorporating Carbon Capture and Storage (CCS) and the use of carbon less or low-carbon alternative energy sources. However, the additional infrastructure and equipment is required for both the cases.

International Panel of Climate Change, IPCC, prepared by the United Nations', highlights that the various parameters on climate change and mentions that the world society responds to the serious issues. In the US, the China and the European Union, policies have been articulated with the main objective of diminishing the CO_2 emissions and in many nations; as part of the global response to climate change, the policies are being introduced to increase the share of non-conventional energy sources. The major challenge in implementing the

RES in to the power system is its intermittent nature. In [1], the authors reviewed that the progress of generation expansion planning methods in the face of more rigorous environmental policies and upward uncertainty. Particularly, the author emphasized the emergent challenges were discussed by the intermittent nature of some RES and also discussed the adequacy of power supply and issues of operational flexibility introduced by variable RES as well as the attempts made to address them. The GEP problem had been solved by us for Tamil Nadu an Indian state, for the time span of 30 years between 2012 and 2041 using a Wien Automatic System Planning IV package. We calculated that the following parameters such as reliability criteria, energy not served and also loss of load probability. we reported that if the RES penetration increases more than 20% of the total installed capacity, the system reliability will fall and uneconomical because huge amount of back-up capacity required to maintain the required reliability level, it required huge amount of investment cost[2]. Then we analyzed the economic and environmental influence of RES introduction into TN power system using LEAP with integration of both Demand Side Management (DSM) and Supply Side Management (SSM) strategies. We found that with implementation of DSM and SSM strategies pollutions emitted from the plants, installed capacity requirement can be considerably reduced and also reliability of the system can be improved further [3]. In [4], a LEAP model is used to differentiate the future electric energy demand and supply patterns, as well as emissions of greenhouse gas, for number of alternative scenarios of energy policy and energy sector evolution of Taiwan. The authors have verified that the increasing energy efficiency by 2% annually by the development and adoption of effective energy conservation policies in Taiwan, the CO_2 emissions and the level of Taiwan's energy imports can be significantly reduced. The modeling studies have been carried out to demonstrate the impact of fetching in solar power plants into the system as a technology alternative power plant. The impact of the adding of solar power plants is examined, for 6-year and 14-year planning horizons, using the model formulated, integrating all critical elements of the system, employing Differential Evolution algorithm [5]. In next few decades, all the developed and developing countries are increasing the share of renewable installation capacity and to fully dependent of Renewable Energy Electricity (REE). Recent years many research works is going on to design the solar panel with improving the efficiency. The renewable energy price will come down the level of existing price of conventional energy and the present market status, the power generated from the REE is more costly but the uptake of such technology is expected to decrease during the next couple of decade especially those region having the high irradiation of solar & natural sources are available for long duration and continuous pressure for implementation of numerous RES generation technology, reduce the CO_2 emission and its harmful effect to the environment can be decreased [6]. In Denmark, they are planning for a 100% renewable energy system and research were carried out the possibility of such a system and the results show that it will be achieved in the year 2050 [7]. Aghaei, J., et al. developed a model for GEP problem as multi objective optimization problems which optimize simultaneously multi objectives as minimization of total costs, emissions, energy consumption and portfolio investment risk as well as maximization of system reliability [8]. In [9], Wang, Kefan, et al analyzed the causal relationships between the growth of economic, energy consumption, and CO_2 emission in China between the year 1978 and 2012 by using both the linear and nonlinear causality tests. The obtained results show that both linear and nonlinear causality tests indicate a unidirectional causality from CO_2 emission to GDP and a bi directional causality between energy consumption and CO_2 emission.

In this research work, Long-range Energy Alternative Planning (LEAP) software has been used for solving the GEP problem and it is solved for the state of Telangana for fifteen years from 2016 to 2030. The solutions obtained for various scenarios such as Green House Gases Mitigation Scenario (GHGMS), Low Demand Growth Scenario (LDGS) and two different High Demand Growth Scenarios (HDGS1 and HDGS2) in addition to Reference Scenario (REFS). In all scenarios, the various system performance factors like installed capacity required, emission of pollutants, reliability and total cost are analyzed. The rest of the paper is as follows. The chapter 2 describes about TS power system and chapter 3 describes the implementation of this proposed work in LEAP model. The chapter 4 describes a detailed result and discussions and chapter 5 concludes.

2. Telangana state (TS) power sector

Telangana State (TS), located in Southern region of India, roughly extends between 17.366° N latitude to 78.475° E longitude. In accordance with the provisions of the Andhra Pradesh Reorganization Act 2014 (Act 6 of 2014), attested by the President of India on 1st March 2014, the state of Telangana came into existence on 2nd June 2014 as the 29th and youngest state of India, when it was carved out of the north-western hinterland of Andhra Pradesh. TS is bordered by the states of Maharashtra to the north and northwest, Chhattisgarh to the north, Karnataka to the west and Andhra Pradesh to the east and south. The capital of TS is Hyderabad, associating in the centre portion of the state. TS is the 12th largest state in area and populous in India. As per the provisions of Electricity Act 2003, there are three independent unbundled utilities operational in state namely:

- **Generating Company**

  Telangana State Power Generation Corporation Limited (TSGENCO)

- **Transmission Company**

  Transmission Corporation of Telangana Limited (TSTRANSCO)

- **Distribution Companies**

  Southern Power Distribution Company of Telangana Limited (TSSPDCL)

  Northern Power Distribution Company of Telangana Limited (TSNPDCL)

The total installed capacity of the TS is 12691 MW in which coal based plants contribute 59% and Gas plants contribute 12%, totaling 71%. These two plants are the main contributors for GHG emissions in their state. The share of renewable energy sources including hydro plants is 28%. The rest is shared by both nuclear and oil plants. The technology wise installed capacity of the TS power system is mentioned in the Table 1 [10]. Figure 1 shows the fuel mix ratio of TS power system for the base year.

Table 1
Installed capacity (MW) for TS in 2016 (As on 31.01.2017)

Sector/Plant	Installed capacity, MW						
	Coal	Gas	Diesel	Nuclear	Hydro	RES	Total
State	5406.59	-	-	-	2245.66	-	7652.25
Private	270.00	1570.89	19.83	-	-	1230.21	3090.93
Central	1799.88	-	-	148.62	-	-	1948.50
Sub-Total	7476.47	1570.89	19.83	148.62	2245.66	1230.21	12691.68

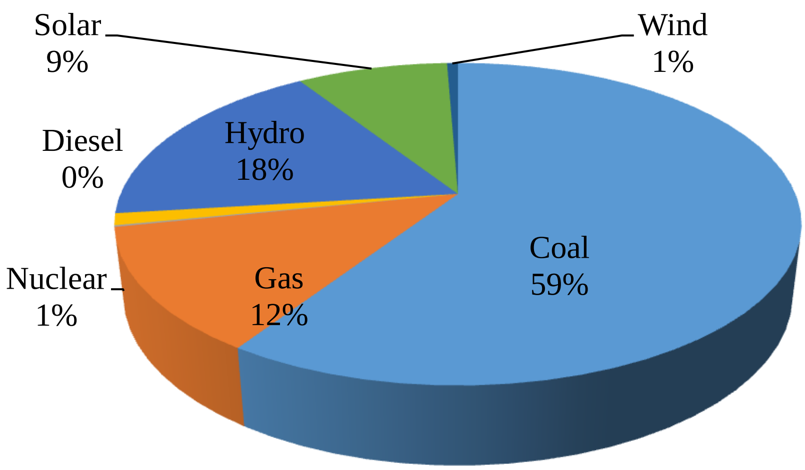

Figure 1: Fuel Mix Ratio in the year 2016

3. Implementation of proposed work in leap

In this research work, LEAP software is used to solve the Generation Expansion Planning problem for Telangana power system for the duration of fifteen years from 2016 to 2030. LEAP is widely used software for energy policy analysis and climate change mitigation assessment [11].

3.1 Load data

The daily load demand details for TS power grid are available in [12]. The maximum demand of 8284 MW occurred in the month of September 2016 and minimum demand of 6114 MW occurred in June 2016. The annual load factor is 85.9%. The load pattern of TS power system in 2016 is shown in

Figure 2.

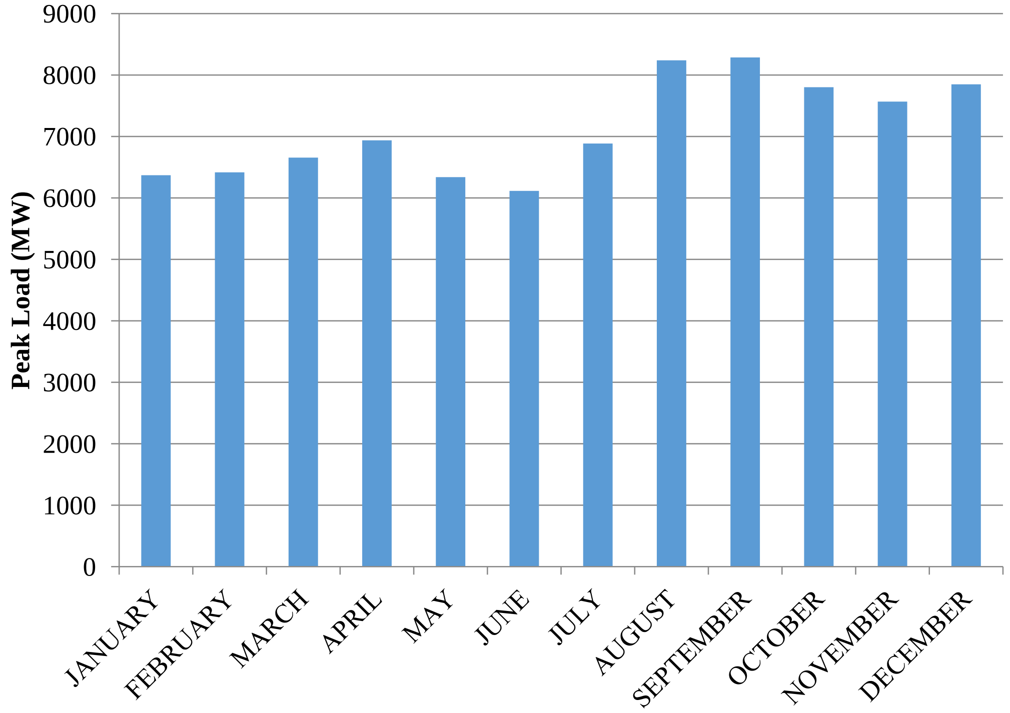

Figure 2 Load profile in 2016

3.2 Exogenous capacity

Table 2 shows the technical and cost data of existing plants. The cost data and plant availability are taken from [13]. The technology wise installed capacity is also shown in the table. The total installed capacity of TS power system is 12691 MW as on January 2017.

Table 2
Technical and cost data of existing plants

Sl. No	Name of the plants	Capacity (MW)	Capital cost ($/kW)	Fixed OM cost ($/kW-Year)	Variable OM cost ($/MWh)	Availability (%)
1	Coal	7476.47	2934	37.80	4.47	73
2	Gas	1570.89	917	13.17	3.60	58
3	Diesel	19.83	850	17.00	25.79	46
4	Nuclear	148.62	5530	93.28	2.14	86
5	Hydro	2245.66	2936	14.13	0	35
6	Solar	1073.41	3873	27.750	0	40
7	Wind	77.7	2213	39.55	0	19

3.3 Endogenous capacity addition

Six various technology based power plants are considered in this research work for future expansion of TS power system. The technical and cost data of expansion candidates are shown in Table 3. For Reference scenario, all the plants are considered except bio mass. This is because of no installed capacity from bio mass in the base year. For GHG Mitigation scenario, renewable energy based power plants is considered as expansion candidates to meet the future load growth; they are on- shore wind plants, solar plants and bio mass plants. In addition to renewable plants, LNG is also taken in to account due to its quick start up characteristic. This is particularly more important to meet the demand whenever power generation from renewable is reduced due to its intermittent in nature.

Table 3
Technical and cost data of candidate plants

Sl. No	Name of the plants	Capital cost (k$/MW)	Fixed OM cost (k$/MW)	Variable OM cost ($/MWh)	Availability (%)	Reference, other scenarios	GHGM scenario
1	Wind	2213	39.550	0	19	√	√
2	Solar	3873	27.750	0	40	√	√
3	Bio mass	4114	105.63	5.26	30	×	√
4	Coal	2934	37.80	4.47	75	√	×
5	Nuclear	5530	93.28	2.14	90	√	×
6	LNG	917	13.17	3.60	65	√	√

3.4 Energy growth

In the base year, the total energy demand for TS power system is 56499 GWh [14]. The average annual energy growth is assumed as 6% based on the past load data. The expected energy demand in 2030 is 127,700 GWh. It is shown in Figure 3.

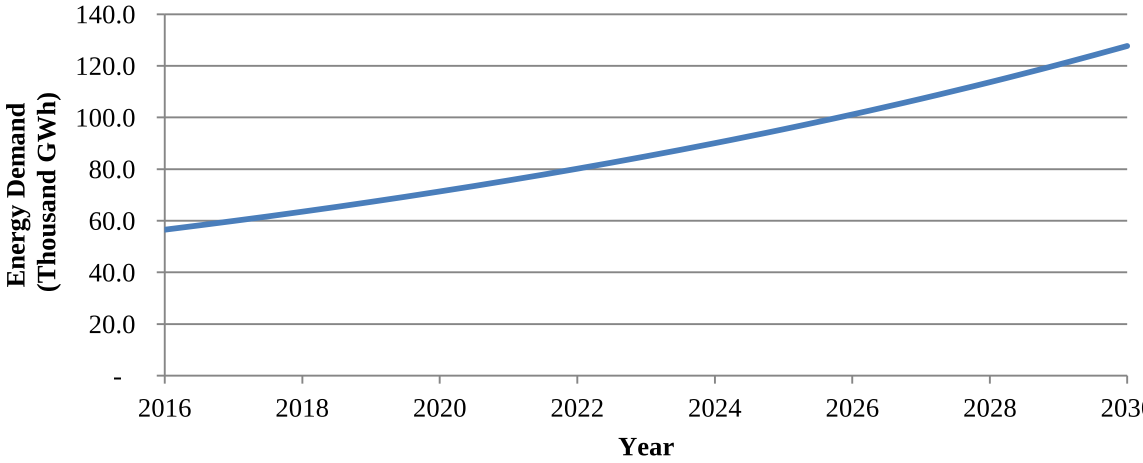

Figure 3 Expected energy demand

4. Results and discussions

In this chapter results obtained by LEAP software such as, installed capacity, Reliability analysis, Net Present Value and environment analysis are discussed for the REFS, GHGMS, LDGS, HDGS1 and HDGS2 scenarios.

4.1 Installed capacity

Table 4 shows the total installed capacity for all scenarios during 2016-2030. There is a sharp increment in capacity additions of 7416.7 MW for REFS scenario and it is 9857.1 MW for GHGMS scenario in 2017. The installed capacity for every scenario compared with REFS. In the year 2030, the installed capacity of the scenarios REFS, GHGMS, LDGS, HDGS1 and HDGS2 are 30,559.4 MW, 36,612.60 MW, 29,455.4 MW, 35,269.7 MW and 38,969.7 MW. When compared with REFS, the GHGMS, HDGS1 and HDGS2 increased by 19.81%, 13.4%, 21.6% respectively and LDGS decreased by 3.6%. The estimated total installed capacity is at the end of study period is shown in Figure 4.

Table 4
Installed capacity (MW) required for all scenarios

	Scenario				
YEAR	REFS	GHGMS	LDGS	HDGS1	HDGS2
2016	12,612.60	12,612.60	12,612.60	12,612.60	12,612.60
2017	20,029.20	22,526.90	20,091.20	20,091.20	20,112.60
2018	20,029.20	23,626.90	21,234.00	21,234.00	21,212.60
2019	21,212.60	23,626.90	21,234.00	22,448.30	22,426.90
2020	21,212.60	24,398.30	21,605.40	22,448.30	23,712.60

2021	22,518.10	25,648.30	22,498.30	23,805.40	24,176.90
2022	22,518.10	26,305.40	22,841.20	24,362.60	25,391.20
2023	23,945.90	27,655.40	23,941.20	25,612.60	26,641.20
2024	24,320.50	28,484.00	24,398.30	26,726.90	28,041.20
2025	25,449.10	29,612.60	25,526.90	28,369.70	29,684.00
2026	26,274.50	31,541.20	25,741.20	29,298.30	31,398.30
2027	27,038.80	32,305.40	26,526.90	30,691.20	33,184.00
2028	28,029.20	33,476.90	27,526.90	32,119.70	35,041.20
2029	29,359.40	35,384.00	28,455.40	33,769.70	36,969.70
2030	30,559.40	36,284.00	29,455.40	35,269.70	38,969.70

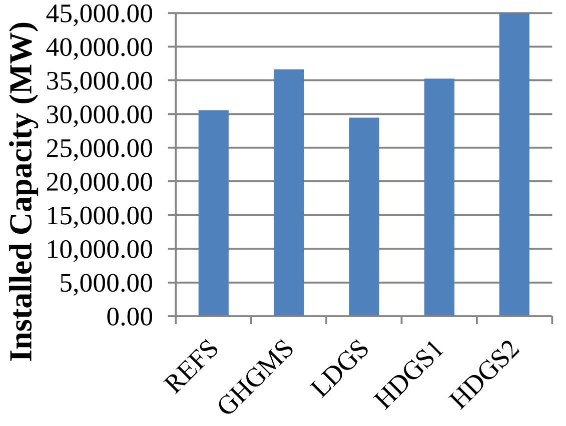

Figure 4 Installed capacity required in 2030 for each scenario

4.2 Reliability analysis

The reliability of the power system is defined as the ability of system to meet the load demand. It is the probability of providing consumers with continuous power supply. It can be measured by various indices in the power system engineering. In this study, Energy Not Served (ENS) is used to evaluate the reliability of the TS power system. The lower value of ENS indicates the better performance (good reliability) of the system and vice versa. The results obtained for reliability index for the system have been presented in Table 5 for all scenarios. The reliability index (ENS) in the base year is 5391.5 GWh. However the reliability of the system can be improved for all proposed scenarios. At the end of the planning horizon this value can be zero for REFS, LDGS and HDGS1 scenarios. The value of this index is 1453.8 GWh for GHGMS, this value may be quite high among the proposed scenarios but it is less than the base year. It is improved by 73% compared to base year index. For HDGS2 scenario, the value of ENS is 139.1 GWh. This is also very low as compared to base year. It means even though the load growth is more; the proposed scenario will be able to meet the demand.

Table 5
ENS values (GWh) of all scenarios

YEAR	REFS	GHGMS	LDGS	HDGS1	HDGS2
2016	5,391.5	5,391.5	5,391.5	5,391.5	5,391.5
2017	-	-	-	-	-
2018	-	-	-	-	-
2019	-	-	-	-	-
2020	-	-	-	-	-
2021	-	-	-	-	-
2022	-	-	-	-	-
2023	-	-	-	-	-
2024	-	-	-	-	-
2025	-	-	-	-	-
2026	-	-	-	-	-
2027	-	-	-	-	-
2028	-	-	-	-	-
2029	-	52.8	-	-	-
2030	-	947.0	-	-	139.1

4.3 Environment analysis

While planning a power system for future, it is essential to analyze the pollution impacts from the thermal plants. The coal and LNG plants are the main contributors to increase in global warming potential. In this study one hundred year Global Warming Potential is quantitatively estimated by using data base used in the LEAP. The Table 5 shows the total GHG emissions from the power plants during the study period. In REFSs, the cumulative GHG emissions are 771 Million Metric Tonnes CO_2 Equivalent. The GHG emission of GHGMS, LDGS, HDGS1 and HDGS2 are 404.7, 749.3, 799.8, 823.6 Million Metric Tonnes CO_2 Equivalent. In GHGMS, it is reduced by 52% when compared to REFS. In GHGMS, it is expected to have less value of GHG emissions due to replacement of thermal plants by

RES type plants like wind, solar and biomass. Among the scenarios proposed in this analysis, GHGMS plays important role in reducing the pollutions and saving the environment. In LDGS, it is reduced by 5.8% when compared to REFS. The pollutants estimated in REFS and HDGS1 scenarios are nearly same at the end of planning period. The HDGS2 scenario has GHG emissions increased by 6.8% when compared to REFS. This result indicates that the necessity of demand side management, it will reduce the pollutants further.

Table 6

Total GHG emissions (Million Metric Tonnes) during the planning period

YEAR	REFS	GHGMS	LDGS	HDGS1	HDGS2
2016	34.1	34.1	34.1	34.1	34.1
2017	43.0	17.8	42.7	43.3	43.5
2018	44.5	17.8	44.0	45.0	45.5
2019	46.0	20.5	45.3	46.8	47.5
2020	47.4	22.0	46.6	48.3	49.3
2021	48.9	22.3	47.9	50.0	51.1
2022	49.7	24.3	49.7	51.6	52.9
2023	51.6	24.8	50.2	53.6	53.1
2024	53.6	27.1	52.4	53.9	55.2
2025	53.9	28.3	52.8	56.3	57.6
2026	56.2	28.5	53.1	58.6	60.3
2027	56.6	31.6	55.6	61.6	63.3
2028	59.4	33.5	56.1	62.0	66.5
2029	62.9	34.5	59.1	65.5	70.0
2030	63.3	37.7	59.6	69.2	73.7

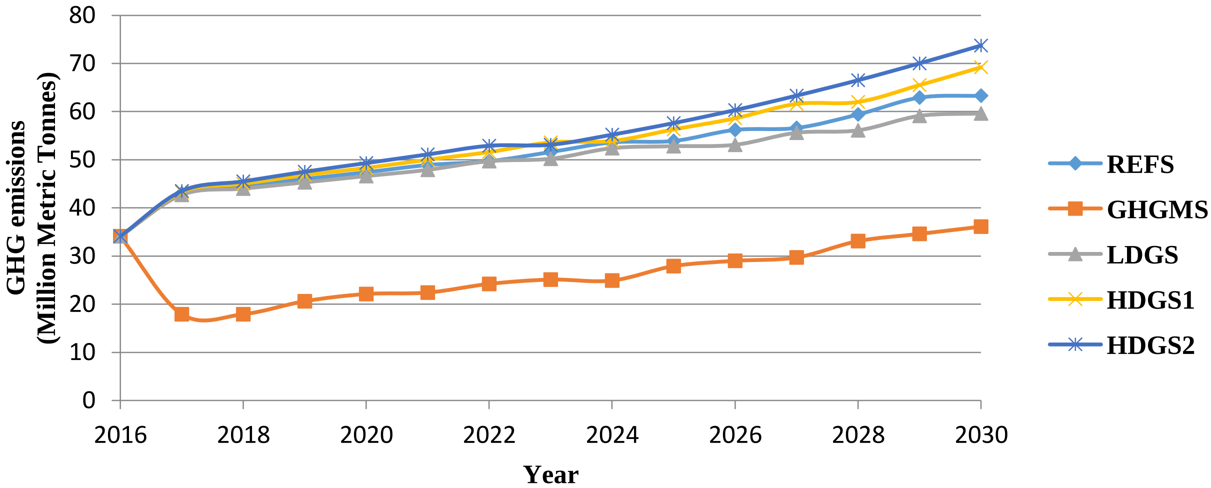

Figure 5 GHG emissions during the planning period

4.4 Net present value

In REFS, the value of NPV is 74.7 Billion USD. The values of NPV are 73.6 Billion USD, 81.9 Billion USD, 86.7 Billion USD and 71.3 Billion USD for LDGS, HDGS1, HDGS2 and GHGMS respectively. The NPV of the HDGS1 and HDGS2 are high compared to all scenarios. It is increased by 8.79% and 13.84% when compared to REFS due to increased demand growth. In LDGS and GHGMS scenarios the NPV values have been decreased by 1.49% and 4.76% respectively when compared to REFS. The Figure 6 shows the NPV values of all scenarios.

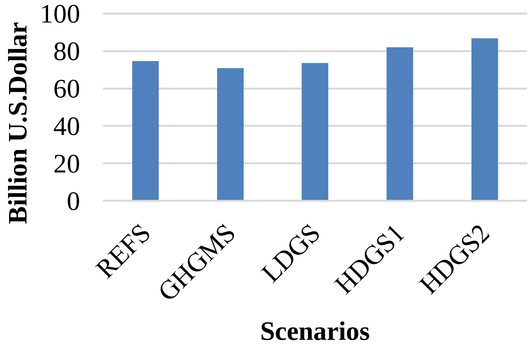

Figure 5 GHG emissions during the planning period

5. Conclusion

In this paper, GEP problem is solved for the state of Telangana, an Indian state for fifteen years from 2016 to 2030. The various scenarios are proposed such as Green House Gases Mitigation Scenario (GHGMS), Low Demand Growth Scenario (LDGS) and two different High Demand Growth Scenarios (HDGS1 and HDGS2) in addition to Reference Scenario (REFS). In all five scenarios, the various system performance factors like installed capacity required, emission of pollutants, reliability and NPV are analyzed using LEAP. The REFS scenario is taken as reference and it is compared with all remaining four scenarios. While considering a performance factor, installed Capacity required, when compared with REFS reference scenario, it is increased by 19.81% in GHGMS scenario, 13.4% in HDGS1 scenario and 21.6% in HDGS2 scenario and it is decreased by 3.6% in LDGS scenario. The obtained results show that, if the demand growth is reduced by 1%, the requirement of installed capacity was reduced by 3.6%. At the same time if demand growth is increased by 1%, it is increased by 13.4%. While analyzing the reliability index for the proposed scenarios, for the given generation mix, it is improved in all five scenarios when compared to the base year. In the case of environmental pollutions, GHGMS has the least effect on the environment and this effect is reduced by 46% when compared to REFS during these study periods. For reduction of 1% in demand growth approximately 3% pollutions are reduced. For 1% increase in demand growth, it is increased by 3.8% for the given generation mix. While considering a performance factor, NPV, for the reference scenario, it is 74.7 Billion USD. For HDGS2 scenario, this value is increased by 16%, whereas LDGS, it is reduced by 5.2%. In future work, uncertainty of RES will be also taken into account and also the effect of storage system on GEP problem will be considered.

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Bibliography

S. SARAVANAN was born in Srivilliputhur, Tamil Nadu, India, in July 1974. He received his B.E. degree in Electrical and Electronics Engineering from Arulmigu Kalasalingam College of Engineering, Virudhunagar District, affiliated to Madurai Kamaraj University, Madurai, Tamilnadu, India, in 1999 and M.E. degree in Power Systems Engineering from Thiagarajar College of Engineering, Madurai, affiliated to Anna University, Chennai, Tamil Nadu, India, in 2007 and Ph.D from Kalasalingam University, Tamil Nadu, India, in 2015.He is a life member of Indian Society for Technical Education (ISTE). Currently he is working as a Professor in the department of Electrical & Electronics Engineering, B.V.Raju Institute of Technology, Narsapur, Telangana, India. He is actively involved in research for the past five years. His current research interests include Load forecasting, Generation expansion planning, Power system operation and control, Power system optimization and Power system problems.

K.KARUNANITHI was born in Aruppukottai, Tamil Nadu, India, in April 1974. He received his UG degree in Electrical Engineering from the Institution of Engineers (India), Kolkata in 2005, M.E. degree in Power Systems Engineering from Thiagarajar College of Engineering, Madurai, affiliated to Anna University, Tirunelveli, Tamil Nadu, India, in 2009 and Ph.D from Kalasalingam University, Tamil Nadu, India, in 2016.
He is a life member of Indian Society for Technical Education (ISTE). Presently he has been working as Professor in the department of Electrical & Electronics Engineering, Siddharth Institute of Engineering & Technology, Andhra Pradesh, India. His current research interest includes Generation expansion planning, energy planning, power system optimization and smart grid.

M .RASUKUTTI was born in Virudhunagar, Tamil Nadu, India, in March 1993. He received his B.E. degree in Electrical and Electronics Engineering from Anna University, University College of Engineering, Ramanathapuram, affiliated to Anna University, Chennai, Tamilnadu, India, in 2014 and he is Pursuing M.Tech. degree in Power Systems Engineering from Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, Tamil Nadu, India. He is actively involved in research for the past two years. His current research interests include Generation expansion planning and Power system optimization.