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Generation Expansion Planning Considering Renewable Energies

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Abstract: - According to need of high investment to construct power plants, the country's generation expansion planning has the particular importance. However, the economic evaluation of distributed generation on power system is an essential step in related studies of this production, in generation expansion planning. In this paper, economic competitiveness of distributed generation and centralized power plants, in the Iranian Power Grid has been analyzed. In order to evaluate the economic justifiably of using these productions, Effective factors in economic justifiably of distributed generation in the development of the power generation system, has been studied using WASP software. Finally, the amount use of the distributed generation capacity and their corresponding costs, Along with the national grid, are compared with each other.

Keywords: - *Distributed Generation, Generation Expansion Planning, Renewable Energy, WASP.*

I. INTRODUCTION

Energy consumption is rapidly increase in development countries, which effects global climate change and global and regional energy management. Among the various kinds of energy carriers, electricity has a special role in helping to attain social and economic development. The problem of power system planning may be classified as generation expansion planning (GEP), transmission expansion planning (TEP), and distribution expansion planning (DEP) [1]. This decomposition is normally performed to make the very highly complex combined problem possible [2].

Generation Expansion Planning (GEP) is considered one of major parts of power system planning issues. The aim of GEP is to seek the most economical generation expansion scheme achieving an acceptable reliability level according to the forecast of demand increase in a certain period of time [3].

The feasibility of the generation structure, the cost of primary energy resources and fuel for the scheme, and the reliability indices of electricity supply, make generation planning a very complicated optimization mathematically [4]. Some of these restrictions have been applied in GEP in the recent literature [5]-[7].

WASP-IV is powerful software developed by International Atomic Energy Agency (IAEA) in which a dynamic programming approach is employed to find an overall optimal required generation capacity for the network so that an index, such as LOLP, is minimized [8].

In using WASP-IV, it is assumed that the fuel cost throughout the geographical distribution of the network is uniform. This assumption is invalid in real life, as allocation of a power plant far from a fuel resource supply center results in high fuel transmission costs. Moreover, in using WASP-IV, a single-node load center is assumed which is not obviously a valid assumption [8]. In other words, while WASP-IV is capable of predicting the overall generation capacity requirements for the grid, it is unable to geographically distribute and allocate the capacities among the areas [1].

Distributed Generation (DG) is an emerging approach to provide electric energy close to load center. Changing economic and regulatory environment and also technological innovations has resulted in a renewed interest for distributed generation in the last decade [9].

DG is a feasible alternative for developing new capacity, especially in competitive electricity networks, from an economic, technical and environmental point of view [10]-[12]. Power system deregulation and the shortage of transmission capacities have led to increase interest in DG sources [13]-[18].

Nowadays, DG is a broadly-used term that covers various technologies; however, it is difficult to find a unique DG technology that takes into account multiple considerations, such as economic, technical, and environmental attributes [10].

Also, it is known that renewable energy such as wind, hydro, solar, and geothermal are relatively expensive and limited in availability. Anyway, to mitigate the environmental impacts to the planet and the risk of depending only on few sources of energy, there is an increasing interest in renewable energy sources [16]. A multistage model for distribution expansion planning with DG is proposed in [19],[20].

This paper is organized as follows: In Section II, the generation expansion planning is described. Section III shows how the optimization problem is formulated, with details of the objective function and constraints imposed. The detail of Iranian Power Grid is presented in Section IV. This paper ends with a presentation of conclusions.

II. GENERATION EXPANSION PLANNING

Generation expansion planning (GEP) problem plays an important role in planning activities and determines which generating units to be commissioned and when to commit online over the long-term planning horizon [1],[2].

The objective of GEP is to minimize the total investment and operating costs associated with the addition of new units and to satisfy the reliability, fuel mix, and the demand criterion. GEP is a highly constrained, nonlinear, discrete optimization problem. The emerging techniques applied to solve GEP are reviewed in [4]. The different metaheuristic techniques have been applied to solve the single-objective GEP problem [6],[7].

The problem to be solved is a generation expansion planning considering the effect of renewable energies. The aim is analysis the economic competitiveness of distributed generation and centralized power plants, in the Iranian Power Grid.

GEP problem is defined as the problem of determining what capacity, which, and when new generating units should be constructed over a long range planning horizon. To achieve this aim, the WASP software using single nodal generation planning model is employed to satisfy the expected energy demand (Fig. 1.).
The problem is supposed to be solved for several years within a specified planning horizon. In doing so, the following points are worth mentioning:

- The planning problem to be solved is of a dynamic type. In other words, the planning horizon is divided into several stages and subperiods of known duration, so the elements to be installed in each stage should be determined. In addition, it is assumed that the predicted load is known for each stage.
- Load Duration Curves (LDCs) represent the operating conditions of power systems over the time; they are obtained from hourly data of demand over a period of time. It can be used in generation expansion planning when all the load and all the generating units are assumed to be connected at the same node (single nodal point generation planning). LDC consists of several levels, as shown in Fig. 2. It is a linear approximation to practical load during curve.
- Spare or redundant capacities in generation and network facilities have been inbuilt in order to ensure adequate and acceptable continuity of supply in the event of failures and Forced Outage Rate (FOR) of plant, and the removal of facilities for regular scheduled maintenance. Therefore, the total outage in the failure events may be due to a forced outrage or a maintenance outage [21]. Those are not neglected in the proposed approach.
- The reliability of generation system configuration is evaluated by WASP in terms of the Loss of Load Probability index (LOLP). This index is calculated in WASP for each period of the year.

As mentioned before, The WASP model has been enhanced to facilitate the work by electricity planners and is currently accepted as a powerful tool for electric system expansion planning [8]. The response space and constraints for solving GEP problem using WASP-IV is shown in Fig. 3. In this figure, PG_{con} represents the installed generation capacity curve of under construction and downtime generating unit in the network in planning horizon. Increasing the curve in some periods, expresses the increase of the capacity of the network due to installed generating units under construction. On the other hand, reducing the curve meant the outage of generating units due to end of their useful life. According to the mentioned issues, the production should be within the range of S (the feasible solution domain). Therefore, with the loss of the network adequacy since t_0, by doing an optimal GEP, PG_{sch} curve is obtained. It represents the installed generation capacity of new scheduled generating units to restore the generation network adequacy.

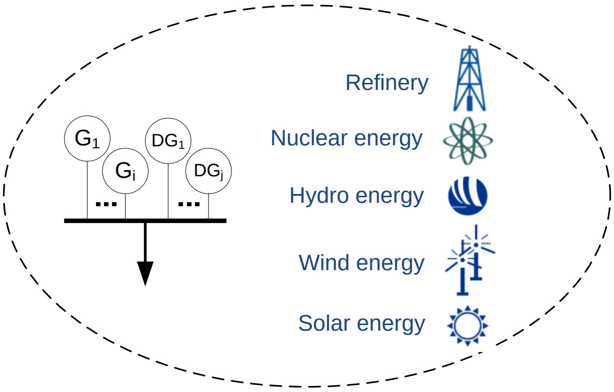

Fig. 1. A single-node sample network.

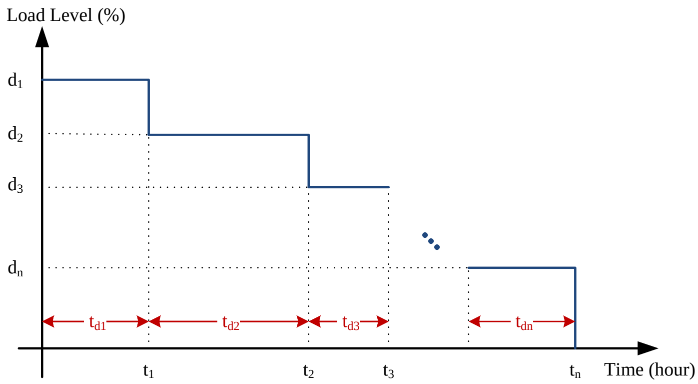

Fig. 2. Linearly approximated load duration curve.

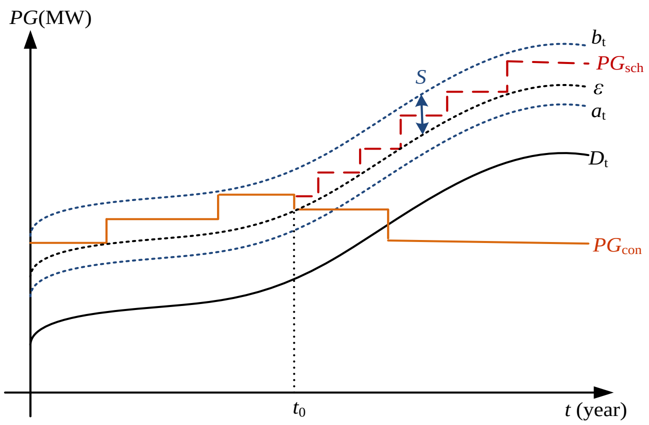

Fig. 3. The feasible solution domain and constraints for solving GEP problem.

III. PROBLEM FORMULATION

The problem as defined in Section II is, in fact, an optimization one to be solved by a proposed solution algorithm. The formulation of the composite expansion planning of generation and transmission line is presented in this section. The objective function terms as well as the various constraints will be discussed in the following subsections.

A. Objective Function

For the long range of planning, the present value of the total cost of engineering project is usually taken as an objective function. Therefore, the objective function to be minimized is the present value of investment and operational costs. This objective function is defined as the total present value sum of the investment cost for new units and the generation costs.

$$z=\sum_{t=1}^{T}\sum_{si}\sum_{b}(I_{tsib}+F_{tsib}+M_{tsib}+O_{tsib}-S_{tsib}) \quad (1)$$

Where I_{tsib}, F_{tsib}, M_{tsib}, O_{tsib}, and S_{tsib} are respectively present value for investment cost in year *t* in bus *b* of generating unit *si*, fuel cost of generating unit *si*, maintenance cost of generating unit *si*, operating cost of generating unit *si*, and salvage value for investment cost of generating. *T* is number of years in a planning horizon.

B. Constraints

The constraints to be observed during the optimization process are as follows:

Generation capacity: the capacity sum of newly installed and existing generating units are more than or equal to the load demand plus reserve in each year within planning period.

$$(1+a_t)D_{ct}\leq PG_{ct}\leq(1+b_t)D_{ct} \quad (2)$$

Where a_t and b_t are respectively Lower bound and Upper bound of reserve margin in year *t;* D_{ct} is forecast peak demand in the critical period of year *t;* and PG_{ct} is Installed generation capacity in the critical period of year *t.*

Reliability: the reliability index LOLP is used to evaluate adequacy of generating units.

$$LOLP_{ct}\leq\varepsilon \quad (3)$$

Where $LOLP_{ct}$ is LOLP index of critical period in year *t* and ε is standard level of LOLP index.

The presence of hydro power plants: this constraint expresses the maximum energy obtained from a hydro power plant in the different periods of the planning horizon at different climatic conditions.

$$PG_{hc}\times t_d\leq W_{hcdt}^{\max} \quad (4)$$

Where PG_{hc} is installed generation capacity of hydroelectric plant *h* in hydrological condition *c*, t_d is duration of subperiod *d,* and $W_{hcdt}^{\max}$ is maximum energy enhanced from hydroelectric plant *h* in hydrological condition *c* in subperiod *d* in year *t.*

Fuel constraint: maximum fuel supply of different fuel types of thermal plants.

$$\sum_{i}F_{ifd}\leq F_{fd}^{\max} \quad (5)$$

Where F_{ifd} is fuel consumption type *f* of thermal unit *i* in subperiod *d* and $F_{fd}^{\max}$ is maximum fuel type *f* available in subperiod *d*.

Emission constraint: maximum production rate of pollution.

$$\sum_{i}E_{iedt}\leq E_{edt}^{\max} \quad (6)$$

Where E_{iedt} and $E_{edt}^{\max}$ are total emission type *e* of generating unit *i* and Maximum emission type *e* in subperiod *d* in year *t,* respectively.

Repairing time of different types of generating units:

$$\textit{Repairing time for each unit}\geq\textit{Required maintenance time} \quad (7)$$

Maximum number of generating units in each period throughout the planning horizon.

$$NG_{it}\leq NG_{it}^{\max} \quad (8)$$

Where NG_{it} is number of new generating unit *i* constructed in year *t* and $NG_{it}^{\max}$ is maximum number of allowed generating unit *i* constructed in year *t*.

IV. IRANIAN POWER GRID

To validate the mathematical model given in section III, the Iranian power grid as a large scale system is considered. Iran is a vast country that has extensive resources of fossil fuels. Major fuel resources are located in the southern part of the country. In the previous years, these resources have been transferred by the oil and gas pipelines to most parts of the country [1].

As Fig. 4 shows, the power plants under construction, cannot supply the system demand until the end of the study period (2025). Due to the complexity of the production facilities technology and electric power transmission, construction of new electrical facilities is very time consuming. Therefore, it is essential that other plants should be added to the production system in addition to the mentioned plants.

Candidate plants specifications considered in this paper, in accordance with the Table I, are introduced into the software. The candidate plants includes the 325 MW steam units (S325), 130 MW big gas units (G130), 400 MW combined cycle units (CC40) and distributed generations (DG30). The WASP software will specify the optimal development of production systems with selecting adequate capacity and types of the candidates, in terms of presence or absence of distributed generations according to system requirements.

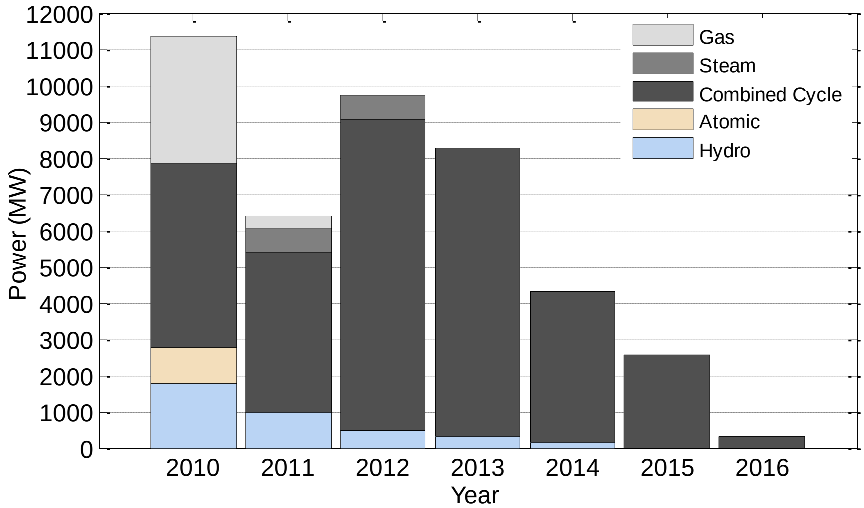

Fig. 4. Approved projects of generation capacity of under construction units by 2016.

TABLE I TECHNICAL AND ECONOMIC ATTRIBUTES OF CANDIDATE GENERATING UNITS

Attributes	Type of Generating Units			
	S325	G130	CC40	DG30
Generation range (MW)	325	130	400	30
Installation lead time (Yr)	5	2	5	1
Life time (yr)	30	15	30	23
F.O.R. (%)	12.9	10.2	13.67	4.95
Maintenance (hr/yr)	56	40	43	7
Capacity factor (%)	92	62	76	69
Efficiency (%)	38.5	33.4	50	51
Investment cost ($/kW)	800	500	850	713
Fix operation and Maintenance cost ($/kw-month)	0.28	0.11	0.11	0.01
Variable operation and Maintenance cost ($/kw-month)	0.36	1.23	0.90	0.018
Allowed installed generating units in RECs	5	10	3	20

Due to global fuel crisis and environmental issues such as restrictions on greenhouse gas emissions, among the technologies used in distributed generation, the renewable energies are especially important. Although renewable energy sources such as wind, photovoltaic, fuel cell and ... Are relatively expensive, but into the reasons mentioned, the increasing desire to develop these resources exist. Although renewable energy sources such as wind, photovoltaic, fuel cell and ... are relatively expensive, but according to the mentioned reasons, the increasing desire exist to develop these resources.

It is known that renewable energies such as wind, solar, and geothermal are relatively expensive and limited in availability. However, to mitigate the environmental impacts to the planet and the risk of depending only on few sources of energy, there is an increasing investment in renewable energy sources. Based on calculations, Iran enjoys only a moderate supply of wind power, though some regions have continuous airflows with sufficient energy to produce electricity. The potential capacity of wind power is figured at about 6500 MW for the country, mostly in the eastern sections [10]

The DG technologies that are considered as alternatives in this comparative assessment are: Wind Technology (WT), Photovoltaics (PV), Fuel Cell (FC) and Microturbine (MT).

In this paper, the mean of technical and economic values of these technologies, according to the Table II, are used as the distributed generation to perform generation expansion planning.

TABLE II TECHNICAL AND ECONOMIC ATTRIBUTES OF CANDIDATE DGS

Attributes	DG Technologies			
	WT	MT	CT	DE
Installation lead time (Yr)	12	1	9	7
Life time (yr)	20	20	30	20
F.O.R. (%)	3.2	6.7	4.2	5.7
Maintenance (hr/yr)	40	20	350	250
Capacity factor (%)	30	95	70	80
Efficiency (%)	40	82	42	40
Investment cost ($/kW)	1000	950	550	350
Fix operation and Maintenance cost ($/kw-month)	0.01	0.01	0.01	0.01
Variable operation and Maintenance cost ($/kw-month)	0.01	0.014	0.024	0.025

The planning horizon is 16 years and each year is divided into four subperiods and considers three load levels. The first stage starts at the base year. The annual rate of interest on capital was set at 10%, with present value factors for the costs of investment and operation. General information required to perform this study is presented in Table III.

With rapid annual growth of 5% - 8% electric consumption, the grid is confronted by a challenging planning problem for the years to come. Table IV gives the peak load ratio for each subperiod. Linearly approximated load duration curve is shown in Fig. 5. In this study, LDC is considered as a three-piece linear approximation.

From 56181 MW installed generation capacity in the Iran Power Grid at the end of 2009, thermal (86.2%), hydro (13.7%), and miscellaneous (1%) are distributed geographic-ally among 16 RECs [8]. Due to the complexity of the generation facilities, the construction of new electrical facilities is very time consuming. If the country is faced with the blackouts phenomenon due to lack of generation facilities, solving the problem in the short term, even with extra spending, is simply not possible. Therefore, new generating units must be added to the grid in addition to the existence units.

TABLE III GENERAL INFORMATION

Parameter	Value
Study period	2010-2025
Planning horizon	2025
Number of periods in year	4
Annual rate (%)	10
Annual rate (%)	10
Minimum reserve margin (%)	10
Maximum reserve margin (%)	30
Critical LOLP (%)	0.05

TABLE IV PEAK LOAD RATIO FOR EACH SUBPERIOD

Period	**Peak Load Ratio**
1	0.8996
2	1
3	0.8936
4	0.8348

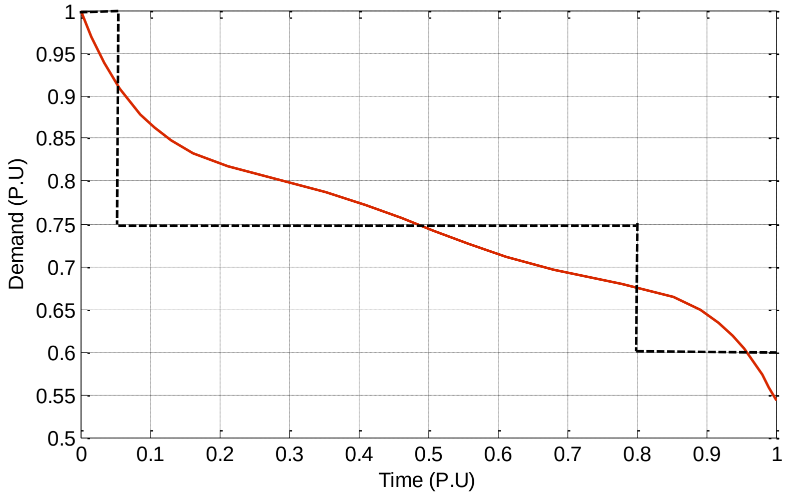

Fig. 5. Linearly approximated load duration curve of the Iranian power grid.

As shown in Fig. 6, total generation capacity of the existence and under construction units, would NOT provide the generation grid constraints until the end of the planning horizon. In this figure, PG_1 represents the installed generation capacity curve of under construction and downtime generating unit in the network in the planning horizon.

V. ANALYSIS OF THE IRANIAN POWER GRID WITH DISTRIBUTED GENERATION

In this section, according to the descriptions and information presented in the previous section, generation expansion planning considering distributed generation have been implemented to Iran Power Grid.
In this section, the results of the WASP software to determine the optimal development scheme of the generation networks with distributed power generation are given in four different scenarios during the period of 2010 to 2025. It is noted that the approved power plans by Ministry of Energy to expand generation capacity by 2016, in accordance with the Fig. 4 is introduced to the software.

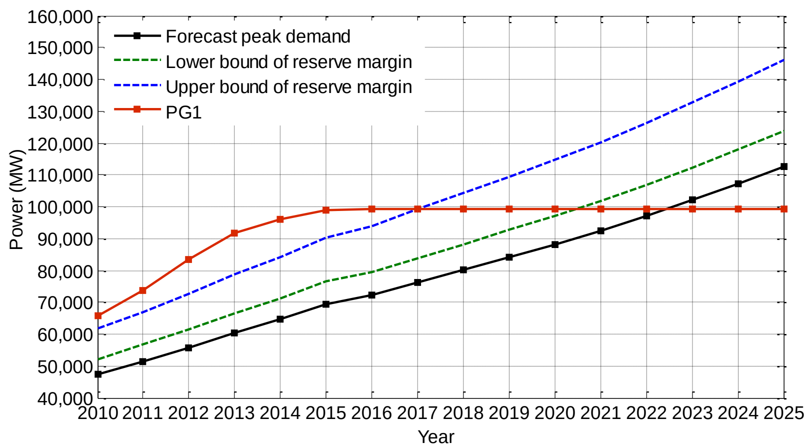

Fig. 6. Iranian Power Grid situation in planning horizon.

Due to the nature of distributed generation, distribution networks are considered as the most appropriate location to connect them to the power system. In addition to distribution feeders, which almost all research done in the field of distributed generation allocation has been assigned to them, the above distribution posts can be suitable for construction distributed generation from the perspective of distribution companies. No need to considerable expansion of the transmission network and reduce the costs related to expansion of these networks, along with reduced losses, are some advantages of the distributed generation.
In this section, with respect to the description of the previous sections, to evaluate the competitiveness of distributed generation on generation expansion planning of power networks, four scenarios have been designed and implemented and their results will be described in the following. For this purpose, at first an option has been selected as the base, then tried to study the justification of the power plant in the different scenarios.

Terms of each scenario are:
Scenario 1) consider the base state of the system
Scenario 2) the effect of non-implementation of the approved construction program
Scenario 3) the impact of increasing transmission costs associated with implementation of centralized power plant
Scenario 4) the combined effects of non-implementation of the approved construction program and increasing trans-mission costs associated with implementation of centralized power plant.
More scenarios features are detailed in Table V.
It can be seen that in the first scenario, 5 steam units, 301 big gas units, and 5 distributed generation units with the total capacity of 40,905 MW are selected and used by 2025 in addition to existing and under construction power plants. The average annual value of LOLP is equal to 0.26, which is equivalent to the blackouts probability of 0.94 day of the year. The cumulative present value of total costs is 38.26 billion dollars that is in fact the lowest cost to develop the system.
Any further capacity intent to improve the reliability or the less capacity to lower investment costs, thereby increasing the total cost of the system. Results of other expansion planning scenarios are presented in the Tables VI and VII.
As is observed, considering the technical advantages, especially the Establishment Location of distributed generations in the fourth scenario, 16 renewable energy units with total capacity of 480 MW by 2025 is scheduled for construction. Figures 7-10 show the new generation capacity planned for each year and Figures 11-14 show the network status of Iran's power grid in every scenario.
By doing the optimal GEP, as shown in Fig. 7, the total installed generation capacities of new scheduled generating units restore the generation network adequacy. It represents with PG_2 in this figure. It is obvious that, with regard to the environmental impacts, feasibility of DGs based on renewable energy technologies, will considerably increase.

TABLE VI GENERATING UNITS AND DGS REQUIRED FOR THE PLANNING HORIZON

	Type of plants	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Scenario 1	S325	0	0	0	0	0	0	0	0	0	0	0	4	0	1
	G130	0	0	0	0	0	0	23	36	37	40	41	34	46	44
	CC40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DG30	0	0	0	0	0	0	0	0	0	0	0	0	0	5
	LOLP	0.001	0.000	0.002	0.005	0.000	0.203	0.494	0.482	0.495	0.484	0.495	0.500	0.492	0.492
Scenario 2	S325	0	1	0	0	0	0	0	0	0	0	0	1	0	0
	G130	0	6	24	35	25	37	36	36	37	39	41	41	45	46
	CC40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DG30	0	0	0	0	0	0	2	0	1	1	2	1	2	7
	LOLP	0.361	0.480	0.498	0.488	0.500	0.492	0.499	0.488	0.495	0.499	0.497	0.495	0.498	0.497
Scenario 3	S325	0	0	0	0	0	0	0	0	0	0	2	1	1	7
	G130	0	0	0	0	0	0	23	36	37	39	37	39	43	31
	CC40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	DG30	0	0	0	0	0	0	0	0	0	2	0	7	1	3
	LOLP	0.001	0.000	0.002	0.005	0.000	0.203	0.494	0.482	0.495	0.494	0.490	0497	0.497	0.496
Scenario 4	S325	0	0	0	0	0	0	0	0	0	0	0	0	2	0
	G130	0	7	25	34	25	37	36	35	37	39	41	43	38	48
	CC40	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	DG30	0	3	0	1	1	0	2	2	2	2	1	2	0	0
	LOLP	0.361	0.494	0.481	0.493	0.496	0.491	0.498	0.497	0.497	0.494	0.499	0.496	0.500	0.499

The Improvement of the proposed approach to determine more details of every region (i.e., R11) is best illustrated by a simple sample as shown in Fig. 8. This figure indicates how to apply the proposed method in the large scale networks.

TABLE V CHARACTERISTICS OF SCENARIOS

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Full implementation of construction of thermal units	100 %	50 %	100 %	50 %
Considering the cost of the transmission network	---	---	50 % of Centralized unit	50 % of Centralized unit

TABLE VII RESULTS OF THE PROPOSED METHOD FOR EVERY SCENARIOS

Parameters	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total cumulative costs ($\$\times 10^6$)	38.26	60.18	44.34	74.96
annual average of LOLP (%)	0.260	0.464	0.260	0.465
Outage period (days per year)	0.94	1.67	0.94	1.67

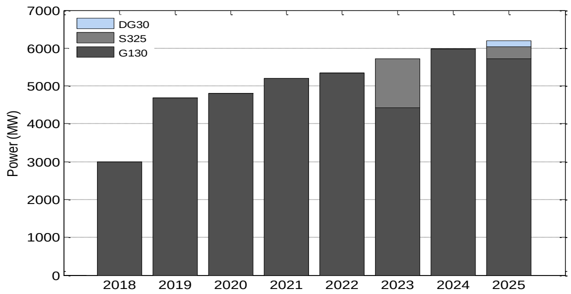

Fig. 7. Capacity of the scheduled power plants in Scenario 1.

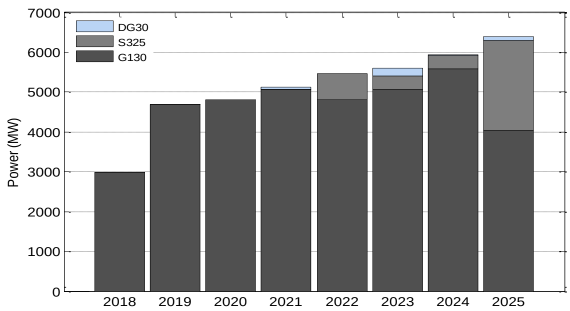

Fig. 9. Capacity of the scheduled power plants in Scenario 3.

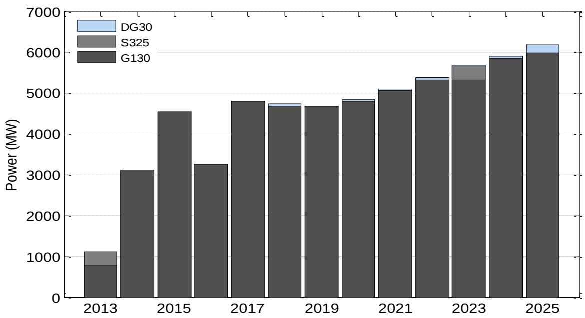

Fig. 8. Capacity of the scheduled power plants in Scenario 2.

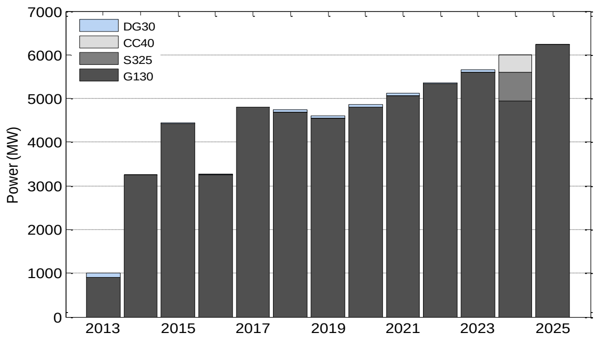

Fig. 10. Capacity of the scheduled power plants in Scenario 4.

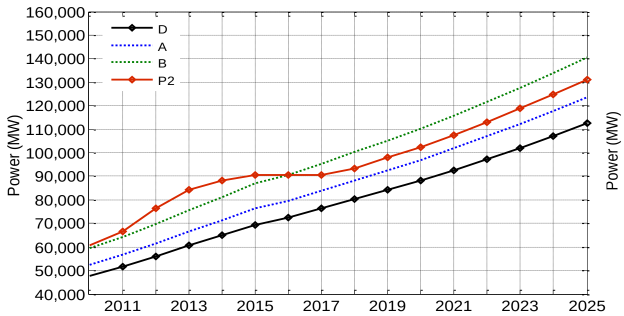

Fig. 11. Expanded Iranian Power Grid situation in planning horizon in Scenario 1.

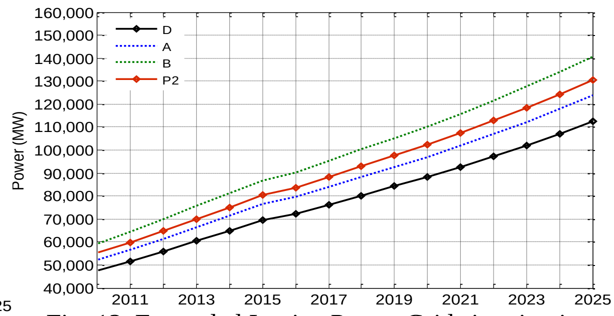

Fig. 12. Expanded Iranian Power Grid situation in planning horizon in Scenario 2.

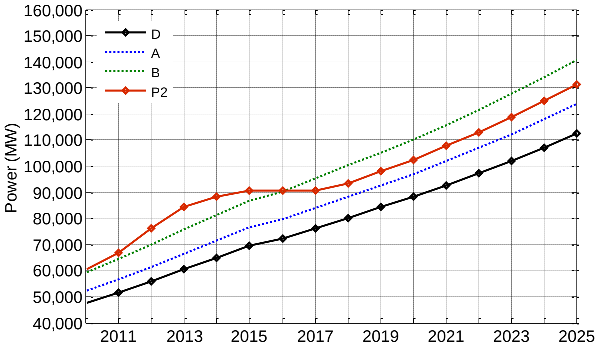

Fig. 13. Expanded Iranian Power Grid situation in planning horizon in Scenario 3.

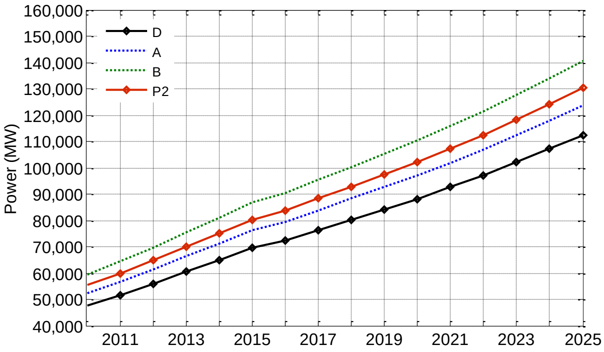

Fig. 14. Expanded Iranian Power Grid situation in planning horizon in Scenario 4.

VI. CONCLUSION

In this paper, the economic competitiveness of distributed generation with centralized thermal power plants was studied in long-term expansion planning. Although the large scale of this issue prevents the use of classical and modern mathematical methods to solve the planning, But in this paper, a part of the facts contained competition distributed generation with centralized power plants included. Due to the importance renewable energies, used these types of technology as distributed generation for long-term generation expansion planning. Considering the technical features of distributed generation in generation expansion planning, especially their construction Location, lead to not additional costs of the transmission network. So, a significant increase of competitiveness between distributed generations with centralized power plants will occur in the country. Therefore if construction of distributed generation done based on technical and economic studies, it would have a significant economic benefit.

VII. ACKNOWLEDGEMENTS

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