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# Generation expansion planning for Iranian power grid aiming at providing reliability by comparing WASP-IV program and proposed algorithm by dynamic programming

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**Abstract**

Generating expansion planning is one of the most significant parts in grid expansion planning. The generating expansion planning extends from 10 to 30 years; reliability is one of the most important constraints in power stations. In generating expansion planning, the loss of load Probability index is one of the most vigorous indices for reliability system. This paper tends to represent primarily generating expansion evaluation with the help of WASP-IV program and proposed algorithm using MATLAB program for Iranian power grid with and without pumped storage power plants within a time period of 10 years (2020- 2020), then the results have been compared.

**Keywords**: Generating expansion planning, Reliability, Loss of load probability, WASP-IV program, Matlab program.

## Introduction

Generation expansion planning is one of the most important parts in grid expansion planning. Its purpose is to find a combination of power plants to obtain consumers needed load effectively and oppose the minimum cost on system for load supply. To accomplish this goal, some considerations should be taken in to account, such as the type of power plant, its capacity, and its time and location settlement. This type of planning is usually carried out for duration between 10 to 30 years (Wang & McDonald, 1994). The barrier that hinders from representing a comprehensive solution for optimization problem is the vast dimensions of the problem caused by a large number of decision-making variables, the existence of constraints, and non linear behavior; however, the proposed methods benefit of simplification for reducing its diminutions (Wang & McDonald, 1994). WASP program is one of the most powerful instruments for generation expansion planning.

The implied assumption in this program is that the total amount of load and all power plants generation are centralized in one bus. This presupposition has brought the reduction of problem dimensions and makes the problem easy to solve (Wang & McDonald, 1994). If the consumers load distribution for intended geographical area or the fuel supply cost is uniform, it will be expected to have the maximum optimization with the help of wasp program. Unfortunately, these assumptions are not always accurate. If modern power plants are located in centers much further away from loads, it will be expected to oppose so much cost to set transmission lines. On the other hand, if these power plants are centralized very closely to load and further from fuel supply, it may lead to enhance fuel cost (Kim, 1993; Wang & McDonald, 1994).So generation expansion planning will not obtain optimal response, otherwise, it regards several considerations including load geographical distribution, constraints on fuel supply, electrical power transmission by transmission lines, and other constraints resulted from geographical limitations, land cost and go forth.

It also should be noted that covering electrical load changes (both time and place) without having auxiliary storage with high capacity seems to be impossible. In similar vein, having intermittent system with long distance is impossible some load changes occur mildly along 24 hours called middle load produced by average load power plants such as hydro-power plants and gas-power plants (power-plants with constant average generation and low variable cost). Some other loads called peak load characterizes with high change that occurs four hours in day. To cover these loads the above mentioned power plants cannot be applied. Among the abundant proposed and used solutions are spinning reserve, using big system with various horizons (extended in geographical altitude), using diesel generators, small hydro-power plants, small gas-power plants, steam power plants with high speed in generation level change, pumped-storage power plants, and so on. Among the electrical storage systems we can refer to super conductive storage system, batteries, dense-air storage system, dense-air storage system inherent in pipes, and pumped-storage power plans (Fukuyama & Ching, 1996; Shively, 2008; Brown*et al.,* 2008).

One of the most prominent constraints in generating expansion planning is validity constraint that is introduced by loss of load probability (LOLP). The present study tends primarily to offer generation expansion evaluation for Iranian power grid and within a time period of 10 years (2010-2020) by using WASP-IV program and proposed algorithm by MATLAB program. This study has been done in two phases, one, with, pumped-storage power plant included and the other without pumped-storage power plants. Then the results have been analyzed and compared. The existence of pumped-storage power plants in Iranian power grid makes serious fall in loss of load probability index shown by means of WASP-IV and

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proposed algorithm within a period of 10 years and finally the results were compared.

**Mathematical modeling for generation expansion planning used in WASP-IV**

WASP program is used for generation expansion planning, and it utilizes minimum cost method for economical evaluation by means of dynamic program. In this program the objective function pertains to minimizing the sum of maintenance cost, fuel, outage and ... in power plants and constraints are characterized by the balance between generation and load, reliability and so on.

*Objective function*

Objective function in wasp programming is minimizing of below relation:

$$Objective\ \ function = \sum_{t=1}^{T} \sum_{j} \left( I_{jt} + F_{jt} + M_{jt} + O_{jt} - S_{jt} \right) \quad (1)$$

In above formulation j, and T represent type of power plants and time period related to case study, and total duration respectively. $I_{jt}$shows power plant cost of J type for tth period, $M_{jt}$refers to maintenance cost of power plant type jfor tth period, $F_{jt}$is fuel cost for power plant type j for tth period, $O_{jt}$ outage cost for power plant type j in tth period, and $S_{jt}$ indicates remained capital cost for power plant type j in tth period. WASP program employs ongoing dynamic method to solve expansion problem. In this method the state of the problem in k+1 is determined based on its state in Kth stage in such a manner that the resulting cost of transmission from K stage to k+1 stage and it's to be minimized.

**Constraints**

Several considerations such as hydro power plant effect, thermo-power plant maintenance planning, and constraints for fuel supply in different seasons have been taken in to account in WASP via dividing one year to several equal periods and studying each period individually. In each year (tth period), the critical period $k_{t,p}$ is the period in which the difference between available generating capacity with one load in a period is maximized. If the peak load in critical period is shown with $D_{t,p}$, the following formulation will be the first constraint considered in WASP as follow.

$(1+a_t)D_{t,p} \le P(k_{t,p}) \le (1+b_t)D_{t,p}$(2)

In this equation P ($k_{t,p}$) represents generation ratio in critical period of tth, that shows the minimum storage, and $b_t$shows the maximum amount of system storage. In WASP, reliability is evaluated by LOLP index that leads to following formulation.

$LOLP(k_{t,p}) \le C_{t,p}$ (3)

$LOLP(k_{t,a}) \approx C_{t,a}$ (4)

$C_{t,p}$ and $C_{t,a}$ are defined as standard amount or acceptable for this index in tth critical period. In each duration, all the components that may meet problem constraints are determined and then the optimal combination is selected based on minimum cost compared with previous period. The following formulation figures out other constraints in WASP.

$U_t^0 \le U_{jt} \le U^0 + \Delta V_t$ (5)

$U_t^0$represents the minimum permitted amount of system arrangement in year the tth. $\Delta V_t$ is a constraint in this index for critical period of the tth. Suppose $k_{jt}$ represents the number of different stages of generating units in implementation of J program in the tth year. So:

$K_{jt} = k_{j,t-1} + A_{jt} - R_{jt} + U_{jt}$ (6)

Where Ajt is vector of generated unit number j that has been developed in t year, Rjt is vector of generated unit number j that has been retired in t year, and Ujt is vector of generated unit number j that has been optimized in t year.

WASP program is characterized with having 12 choices of power plant types. These studies have usually done for duration of several years (up to 30 years). To see the effect of hydro-power plants without constant production that their production is changed seasonally, the studied period, must be less than one year. WASP enables you to divide one year to different unequally periods. In this case, the program attempts to balance load and generating within different periods of time. Considering the total consumption and the way of curve change (LDC curve) different features of power plants including maximum production, production cost, and a combination of new and old power plant are introduced in such a manner that provides not only the balance load and its generation but also the needed cost ratio for setting new power plants, power generation, and maintenance are minimized.

**Case study, the Iranian power plant**

The present paper is a survey on Iranian power grid that its planning procedure has been carried out by the WASP-IV program and proposed algorithm that will be stated in following sections and finally, two methods will be compared.

*The implementation of WASP-IV for Iranian power grid*

The input information of WASP-IV planning has been identified in three modules including loadsys, fixsys, and varsys.

*Fig. 1. Load duration curve for Iranian power grid*

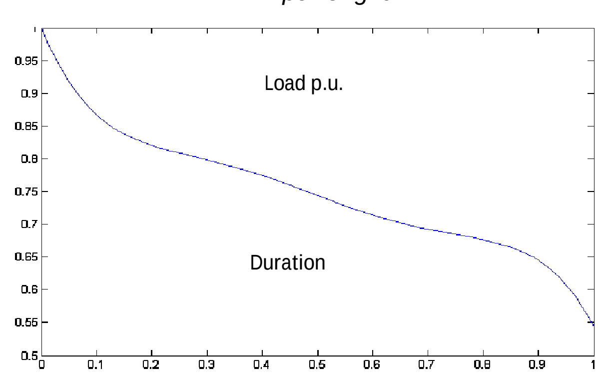

*Table 1. Fuel type*

| Fuel | Name | Short Description | Type |
|---|---|---|---|
| 0 | NUCL | NUCLEAR | Nuclear |
| 1 | HFO | HEAVY FUEL OIL | Mazut Oil |
| 2 | GASO | GAS OIL | Diesel |
| 3 | 1×ml | NG/HFO | Natural Gas, Mazut |
| 4 | 2 ×ml | NG/GO | Diesel, Natural Gas (Combined) |

1. Loadsys: relates to load data in which peak load during the period and curve points in each period have been considered as input data. Four periods (spring, summer, fall, winter), in each period the inherent points in load duration curve have been brought one by one. This curve plays very significant role in determining if and when pumped storage power plants are required. Generally speaking, the more slope a curve, it means the curve is sharper or in other word, the difference between maximum and minimum consumption is higher, the more probable is the justification for requiring pumped storage power plants. The curve LDC for Iranian power grid has been shown in Fig. 1.

*Table 2. Input data wasp relevant to candidate power plants*

| Power plant type | Small gas (G13S) | Big gas (G13B) | Steam (S3) | Combine cycle (CC40) |
|---|---|---|---|---|
| Generating power (mw) | 130 | 130 | 325 | 400 |
| Construction time (year) | 1 | 2 | 5 | 5 |
| Power plan life (year) | 20 | 15 | 30 | 30 |
| Forced outage rated (%) | 9.8 | 10.2 | 12.9 | 13.67 |
| Maintenance time annual average (day) | 35 | 40 | 56 | 43 |
| Domestic consumption (%) | 0.8 | 0.6 | 6.4 | 1.6 |
| Efficiency (%) | 25 | 33.4 | 38.5 | 50 |
| Installed cost ($/KW) | 620 | 1000 | 1733 | 1793 |
| Maintenance cost ($/KW) | 19 | 11 | 34 | 12 |
| Fuel cost (c/million kcals) | 683 | 683 | 569 | 683 |
| Fuel type | 4 | 4 | 3 | 4 |

2**-** Fixsys**:** It identifies information related to existent power plants. The power plants have been classified based on their types, capacity, and number. The maximum types of fuel in WASP are 10 cases. This study considers five types of fuels represented in Table 1.

Most existent huge units in Iranian power grid are characterized as thermal power plants. The most important features of thermal power plants that might be mentioned are forced out put ratio and maintenance program. Moreover, the number of units that should be added or subtracted during this course is also determined. The available number of hydro-power plants has been estimated to 26 divided into two major types including big reservoir and small reservoir. In hydro-power plants properties such as productivity year, settlement capacity (Mw), and storage capacity (Gwh) are identified. Furthermore, the average capacity (Mw) and energy (Gwh) in each period are defined.

3**-**Varsys**:** This term represents information relevant to candidate power plants. They are categorized based on type and capacity. Four candidate power plants are employed in this study; their features resemble inherent thermal power plants that show in Table 2.

*Table 3. pump storage characteristic*

| | Pumping Capacity(MW) | Generation Capacity (MW) | MaxFeasible Energy(GWh) |
|---|---|---|---|
| 1 | 87 | 85 | 160 |
| 2 | 70 | 68 | 140 |
| 3 | 60 | 58 | 120 |
| 4 | 55 | 53 | 110 |
| Fixed O/M Cost $/KW-month | | | 0.358 |
| Installed Capacity MW | | | 250 |
| Cycle Efficiency % | | | 75 |
| Plant life (years) | | | 50 |
| Interest During Construction Included in Capital Cost | | | 19.2 |
| Construction time (years) | | | 5 |
| Depreciable Capital Cost ($/kw) | | | 600 |
| | | | 650 |

This study shed some light on storage system used in pumped storage power plants. One of the wasp qualifications is its capability in offering evaluation for pumped storage power plants considered as candidate power plants for Iranian power grid. Table 3 shows pumped storage power plant characteristics (Schoenung & C. Burns,1996; Malik & Cory, 1991; Hungchen, 2008).

Three major modules of Wasp are CONGEN, MERSIM, and DYNPRO that under take the task of calculations. To sum, CONGEN refers to the number of acceptable components in each period, MERSIM is used for simulation of generating probability, and DYNPRO is associated with optimizing by using dynamic planning. In DYNPRO the optimization is done according to cost.

*The analysis of Iranian power grid without considering of pumped storage power plant:* When obtaining a constraint solution, the optimization results have been acquired. After final implementation of wasp, the optimal results could be visible in reprobate table 4 represents these results.

The candidate power plants include S325 (steam), G13S (small gas), CC40 (combine cycle), and G13B (big gas). The justified numbers for S325, G13P, CC40, and G13B are 3, 18, 48, and 3 respectively. It should be noted that LOLP index is also computed yearly.

*The analysis of Iranian power grid with considering pumped storage power plant:* If pumped storage power plant compatible with information mentioned in table 3 is considered as candidate power plant, the outcomes will be represented in Table 5.

The pump here is introduced as the candidate pumped storage power plant. The justified number of units defined by WASP is 3 for year 2021. In this paper the evaluation for pumped storage power plant is studied as energy storage system. To determine the capacity of candidate pumped storage power plant, three different

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*Table 4. Optimum solution WASP implementation without pumped storage power plants*

| Optimum solution<br>Annual additions: Capacity (MW) and number of units or projects for details of individual units or projects see variable system report & fixed system report for other additions or retirements | | | | | | |
|---|---|---|---|---|---|---|
| Name | | | S325 | G13S | CC40 | G13B |
| Size (MW) | | | 325 | 130 | 400 | 130 |
| YEAR | LOLP | CAP | | | | |
| 2011 | 0.2823 | 530. | | 1 | 1 | |
| 2012 | 0.2811 | 4305. | 1 | 6 | 8 | |
| 2013 | 0.2798 | 1060. | | 2 | 2 | |
| 2014 | 0.2790 | 4370. | | 9 | 8 | |
| 2015 | 0.2732 | 1980. | | 6 | 3 | |
| 2016 | 0.2691 | 3320. | | 4 | 7 | |
| 2017 | 0.2655 | 3850. | | 5 | 8 | |
| 2018 | 0.2513 | 3180. | | 6 | 6 | |
| 2019 | 0.2505 | 4580. | | 26 | 3 | |
| 2020 | 0.2417 | 2740. | 2 | 10 | 1 | 3 |
| 2021 | 0.2403 | 790. | | 3 | 1 | |
| TOTALS | | 30705. | 3 | 78 | 48 | 3 |

states are considered. Pumped storage power plants with capacity of 250, 375, and 750mw have been taken in to account, then the results have been represented in table 6. Characteristics that distinguish pumped storage power plant with 250mw capacity from power plants with 375 and 750mw capacity are rooted in their pump capacity in (MW), productivity capacity in (MW), and the probable maximum energy in (GWh) in each period (Table 6).

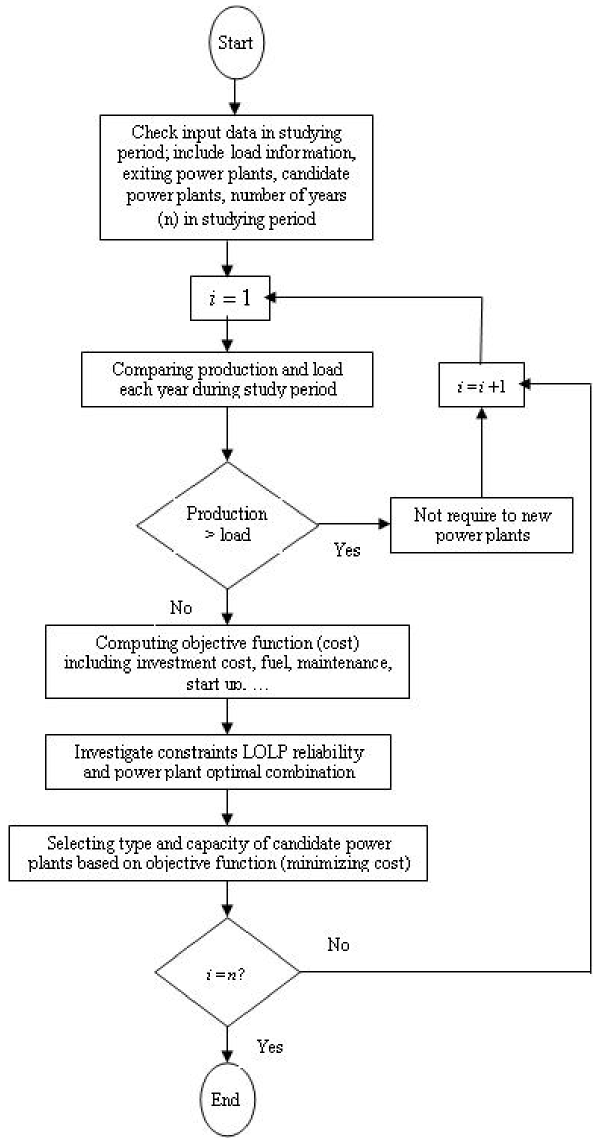
In comparing three above states, the least cost belongs to the first state with considered capacity about 250mw for pumped storage power plant. So, three pumped storage power plants with 250mw capacity are justifiable for Iranian power grid. The results of wasp implementation are shown in Table 5.

*Data analysis*

*Table 5.Optimum solution WASP implementation with considering pumped storage power plants*

| Optimum solution<br>Annual additions: Capacity (MW) and number of units or projects for details of individual units or projects see variable system report & fixed system report for other additions or retirements. | | | | | | | |
|---|---|---|---|---|---|---|---|
| Name | | | S325 | G13S | CC40 | G13B | Pump |
| Size(MW) | | | 325 | 130 | 400 | 130 | 250 |
| YEAR | LOLP | CAP | | | | | |
| 2011 | 0.1173 | 530. | | 1 | 1 | | |
| 2012 | 0.1102 | 4305. | 1 | 6 | 8 | | |
| 2013 | 0.1035 | 1060. | | 2 | 2 | | |
| 2014 | 0.1014 | 4370. | | 9 | 8 | | |
| 2015 | 0.1010 | 1980. | | 6 | 3 | | |
| 2016 | 0.0938 | 3320. | | 4 | 7 | | |
| 2017 | 0.0912 | 3850. | | 5 | 8 | | |
| 2018 | 0.0810 | 3180. | | 6 | 6 | | |
| 2019 | 0.0542 | 4580. | | 26 | 3 | | |
| 2020 | 0.0091 | 2740. | 2 | 10 | 1 | 3 | |
| 2021 | 0.0017 | 750. | | | | | 3 |
| Total | | 30665. | 3 | 75 | 47 | 3 | 3 |

*Fig. 2.The flowchart of proposed algorithm*




According to results mentioned in table 4 and 5 due to the inclusion of pumped storage power plant, we clearly observe the remarkable reduction in LOLP index which is one of the most important benefits of settlement of this type of power plan in Iranian power grid. For example, in 2021 this amount for non pumped storage power plant has been considered about 0.2403 and this amount with pumped storage power plant has been declined to 0.0017, this difference is relevant to high difference between generation and consumption in Iran or, in other words to incoherence of load curve. With the help of pumped storage power plant, the load curve has been thoroughly uniform and reduces the probability of loss load.

**Proposed algorithm for generation expansion planning in Iranian power grid**

In previous section generation expansion

*Table 6. comparing various states of WASP implementation*

| states | type | Capacity (MW) | Justified number | Total cost (Million $) |
|---|---|---|---|---|
| 1 | PS* | 250 | 3 | 8130.9 |
| 2 | PS* | 375 | 2 | 8133.2 |
| 3 | PS* | 750 | 1 | 8133.7 |

*Table 7. The implementation of proposed algorithm without pumped storage power plants*

| | | | Candidate power plants | | | |
|---|---|---|---|---|---|---|
| Name | | | S325 | G13S | CC40 | G13B |
| Size(MW) | | | 325 | 130 | 400 | 130 |
| YEAR | LOLP | CAP | | | | |
| 2011 | 0.2723 | 530. | | 1 | 1 | |
| 2012 | 0.2701 | 4285. | 1 | 10 | 6 | 2 |
| 2013 | 0.2687 | 790. | | 3 | 1 | |
| 2014 | 0.2653 | 4080. | 2 | 10 | 5 | 1 |
| 2015 | 0.2611 | 2175. | 1 | 5 | 3 | |
| 2016 | 0.2549 | 3170. | | 7 | 5 | 2 |
| 2017 | 0.2523 | 3980. | | 6 | 8 | |
| 2018 | 0.2510 | 3190. | | 3 | 7 | |
| 2019 | 0.2474 | 4570. | | 28 | 2 | 1 |
| 2020 | 0.2407 | 2815. | 1 | 12 | 2 | 1 |
| 2021 | 0.2396 | 715. | 1 | 3 | | |
| TOTALS | | 31600. | 6 | 98 | 40 | 7 |

*PS* is pump storage.*

planning has been carried out by means of WASP_IV program. In this part this program utilizes MATLAB program, Fig.2 shows it's correspond flowchart algorithm. In this flowchart you can firstly find input data consisting of load information, existent power plants, and candidate power plant in grid, and intended course duration, then generation and consumption has been compared within each period of time. If the generation rate exceeds consumption, no new power plant is needed; other wise additional power plants should be added.

The objective function considered for this study is intended to minimize cost including, fuel maintenance, and operation. Moreover it must consider constraints. Among the most significant constraints that should be regarded in this algorithm can mention reliability (LOLP) and optimal combination of power plants. Finally, with considering objective function and constrains, type and capacity of power plant for supplying the load are determined.

*The implementation of proposed algorithm for Iranian power grid*

To implement of proposed algorithm two situations are considered.

*The analysis of Iranian power grid without pumped storage power plant:* After implementing the proposed algorithm, the optimal results have been represented in Table 7.

As indicated in above table S325 (steam), G135 (small gas), CC40 (combined cycle), and G13b (big gas) are all candidate power plants. The justified number for power plants S32s, G13P, CC40, and G13B are 6, 98, 40, and 7 respectively. Also LOLP index is obtained in each year.

*The analysis of Iranian power grid with pumped storage power plant:* If pumped storage power plant accompanied by its relevant data in table 3 is considered as a candidate power plant, the results have been shown in Table 8.

Pump is a candidate power plant, and justified number introduced by WASP is three units in 2021. In this study, the evaluation for pumped storage power plant has been surveyed as storage energy system. To determine the candidate pumped storage power plant capacity, three different states including 250, 375, and 750MW have been regarded, and then results have been represented in Table 9. Distinctive features such as pump capacity (MW), generation capacity (MW), and maximum probable energy (GWH) in each period have differentiated between pumped storage power plants with 250 (MWH) and other two pumped storage power plants in 375 and 750 (WMH).

Comparing the three above mentioned states, it is clear the least cost belongs to the first state with pumped storage power plant in 250mw. So, the existence of three pumped storage power plants is justifiable for Iranian power grid.

*Data analysis*

Table 7 and 8 confirms the correctness of proposed algorithm. The existence of pumped storage power plant in Iranian power Grid makes LOLP index reduce seriously that is one of the most significant benefits for pumped storage settlement. For example, without considering pumped storage power plant in 2021, the resulted amount of LOLP index was 0.2396 that the same amount for pumped storage power plant included has been reduced to 0.0019. The reason for this reduction can be pointed as a high difference between generation and consumption. In other words, it refers to incoherent load curve but with using pump storage power plant the load curve is completely uniform and the loss of load probability is decreased.

**Comparison between results from implementing WASP-IV and proposed Algorithm**

Comparing the results from proposed algorithm with generation expansion planning confirms the correctness of proposed algorithm. In this situation e, i, within a period of 10 years the required generation rate is approximately the same. As it has already been mentioned the difference between generation and consumption is highly remarkable in Iran that makes a load curve incoherent. So, pumped storage power plant is used as a candidate power plant to reduce the difference between these two factors. The results show that the existence of pumped storage power plant in Iranian power grid reduces the LOLP index shown in implementation of two programs (WASP-IV and proposed algorithm). The existence of pumped storage power plant makes the probability of load loss decrease which in turn is indicator for reliability improvement.

*Table 8. The implementation of proposed algorithm with considering pumped storage power plants*

| | | | Candidate power plants | | | | |
|---|---|---|---|---|---|---|---|
| Name | | | S325 | G13S | CC40 | G13B | Pump |
| Size(MW) | | | 325 | 130 | 400 | 130 | 250 |
| YEAR | LOLP | CAP | | | | | |
| 2011 | 0.1183 | 530. | | 1 | 1 | | |
| 2012 | 0.1132 | 4305. | 1 | 10 | 6 | 2 | |
| 2013 | 0.1076 | 1060. | | 3 | 1 | | |
| 2014 | 0.1001 | 4370. | 2 | 10 | 5 | 1 | |
| 2015 | 0.0987 | 1980. | 1 | 5 | 3 | | |
| 2016 | 0.0928 | 3320. | | 7 | 5 | 2 | |
| 2017 | 0.0906 | 3850. | | 6 | 8 | | |
| 2018 | 0.0806 | 3180. | | 3 | 7 | | |
| 2019 | 0.0512 | 4580. | | 28 | 2 | 1 | |
| 2020 | 0.0098 | 2740. | 1 | 12 | 2 | 1 | |
| 2021 | 0.0019 | 750. | | | | | 3 |
| TOTALS | | 31635. | 5 | 98 | 40 | 7 | 3 |

*Table 9. Comparing various states of (wasp) implementation*

| States | type | Capacity (MW) | Justified number | Total cost (Million $) |
|---|---|---|---|---|
| 1 | PS* | 250 | 3 | 8137.4 |
| 2 | PS* | 375 | 2 | 8143.1 |
| 3 | PS* | 750 | 1 | 8145.8 |

*PS* is pump storage.*

## Conclusion

Generation expansion planning is a subdivision derived from general problem for power network expansion planning. In this planning the efficiency or qualification of power plant for Iranian power grid in order to supply consumers load has been studied according to reliability constraint. In the case of power plant being in efficient, the generation expansion planning identifies the appropriate types of power plants, their capacity, and time duration to meet designed Efficiency, along with, the minimum cost for operating new power plants. This study primarily represents an evaluation for generation expansion with and without pumped storage power plants by means of WASP-IV program and proposed algorithm in Iranian power grid within a time period of 10 years, and then it compares the results. The existence of pumped storage power plants in Iranian power grid causes to reduce probable index of load loss seriously. This is shown by the help of WASP-IV and proposed algorithm within a time period of 10 years. Finally, the results were compared, and the obtained results confirm the proposed algorithm.

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