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A new algorithm for generation expansion planning aiming at providing reliability by dynamic programming (case study: Iranian power grid)

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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. 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. This study shed some light on storage system used in pumped storage power plants. 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. WASP program is one of the most powerful instruments for generation expansion planning. In this paper is not utilize WASP-IV 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.

Introduction

Generation expansion planning is one of the most important parts in grid expansion planning. The purpose of Generation expansion planning 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 [1]. 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 [1]. 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 [1] that this assume is considered in proposed algorithm. 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 [2]. 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 [1, 3]. 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 [4, 5]. 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 proposed algorithm (dynamic programming) by MATLAB program. This study has been done in two phases, one, pumped-storage power plant is considered and the other, pumped-storage power plants is not considered. 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 proposed algorithm within a period of 10 years and finally the results are compared.

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Mathematical modeling for generation expansion planning

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

Objective Function

Objective function in this algorithm is minimizing of below relation:

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

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 this algorithm as follow.

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

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 this algorithm, reliability is evaluated by LOLP index that leads to following formulation.

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

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

$C_{t,p}$ 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 the proposed algorithm.

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

U_t^0 represents the minimum permitted amount of system arrangement in year the tth. ΔV_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:

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

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.

This algorithm 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. This algorithm enables you to divide one year to different unequally periods. In this case, the proposed algorithm 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 proposed algorithm that will be stated in following sections.

Proposed algorithm for generation expansion planning in Iranian power grid

The present paper is a survey on Iranian power grid that its planning procedure has been carried out by the proposed algorithm that will be stated in following sections. The input information of the proposed algorithm has been identified in three modules including loadsys, fixsys, and varsys.

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.

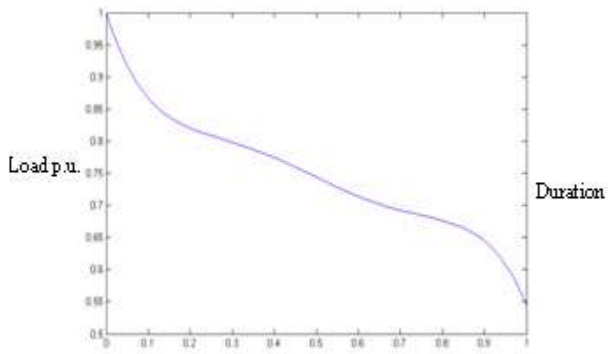

Fig. 1: Load Duration Curve for Iranian Power Grid

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. Four candidate power plants are employed in this study; their features resemble inherent thermal power plants that show in table 2.

This study shed some light on storage system used in pumped storage power plants. Table 3 shows pumped storage power plant characteristics [6, 7, and 8].

In the proposed algorithm for generation expansion planning, MATLAB program is used. Fig. 2 is shown the flowchart of the proposed 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.

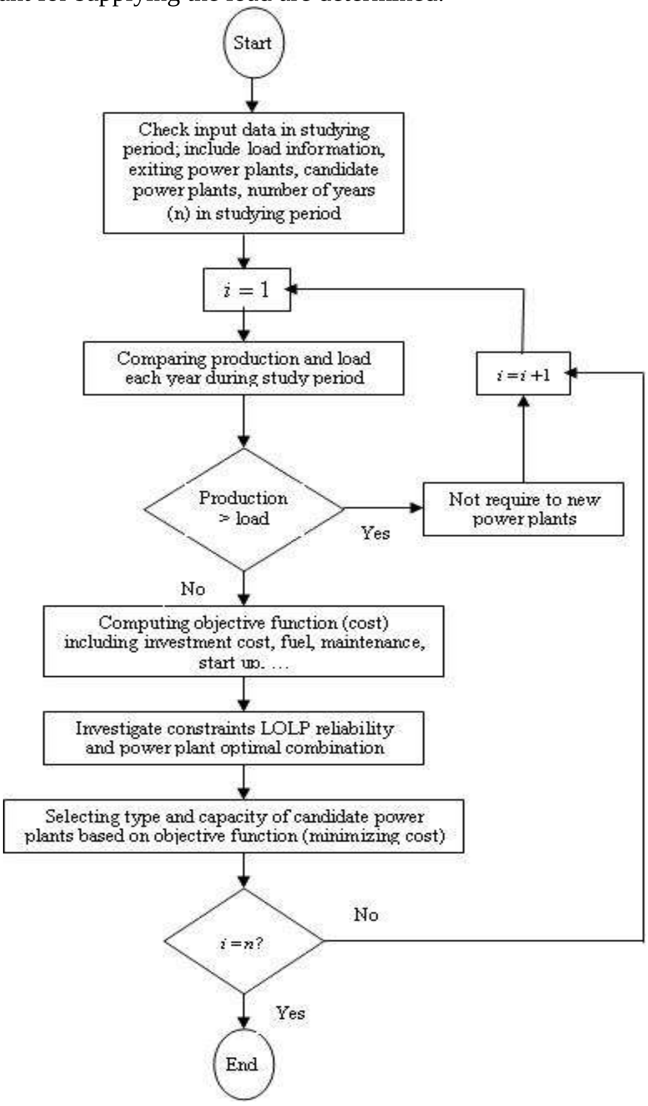

Fig.2: The flowchart of proposed algorithm

The implementation of proposed algorithm to reach optimal solution

The analysis of Iranian power grid without pumped storage power plant

After implementing the proposed algorithm, the optimal results have been represented in table 4.

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 5.

Pump is a candidate power plant, and justified number introduced by the proposed algorithm is three units in 2020. 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 6. 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 37S 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 4 and 5 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.

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 represents an evaluation for generation expansion with and without pumped storage power plants by MATLAB program for 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 proposed algorithm within a time period of 10 years. The obtained results confirm the proposed algorithm.

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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 × mI	NG/HFO	Natural gas, mazut
4	2 × mI	NG/GO	Diesel, natural gas (combined)

Table 2: input data relevant to candidate power plants

Power plant type	Small gas (G13S)	Big gas (G13B)	Steam (S325)	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 (percent)	9.8	10.2	12.9	13.67
Maintenance time annual average (day)	35	40	56	43
Domestic consumption (percent)	0.8	0.6	6.4	1.6
Efficiency (percent)	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

Table 3: pump storage characteristic

Period	Pumping Capacity (MW)	Generation Capacity (MW)	Max Feasible 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)			Domestic	600
			Foreign	650

Table 4: 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

Table 5: The implementation of proposed algorithm with 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 6: 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.