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Evaluation of pump storage power plant for Iranian power grid

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ABSTRACT

Gradual development in power systems has caused so many problems in control and optimum using of electrical storage systems. Storing of electrical energy has made new capabilities in improving the current control methods. Quick access to these kinds of energies lets us direct control for supplying the consumers in electrical grid network. These methods are powerful to control and solve the current economical and technical problems of the compound and large power systems. On the other hand, using the various methods of direct energy storage can produce suitable capacity to store the electrical energy for the power industry. Among all of the energy storage systems, pumped storage power plants when they committed, because of their special characteristics, have a unique situation. In this paper, the feasibility assessment of the usage of pumped storage power plants for the Iranian grid has been discussed by WASP-IV program.

Introduction

One of the sustainable developments of power grid is optimum using of electrical energy. For this we need establish progressed power grid in that regional power grid with high distance from each other have been made and they can use from their electricity storage. These needs come from in spite of other energies, production and consumption of electrical energy can occur simultaneously because of large scales saving of this energy. Thermal power plants and large water power plants act as a main source of power grid, work with a constant load. As above, covering the variation of electricity load (both time and position variations) without having storage with high capacity and having power grids between regions with long distance is not possible. 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. In the [3] this systems from efficiency point of view, capital cost of energy and power, constant and variable cost of maintenance have been compared. With comparison between energy saving systems show that saving pump power plant are a suitable solution for electric energy saving at any situation [1]. Pump saving power plants have many advantage and this important items are: reactive power control ability and power grid voltage control, power consumption in none peak over and uniform of daily load curve, the ability of rapid ejection to the power grid in the high variation of load, important of trust ability in the production systems and decreasing production cost and capital cost [2]. In contrast advantages of pump saving systems have the main default that cause decreasing efficiency of power plants and that is limited use of these systems. Because we use these systems in the end of night hours for pumping water from a storage or pool with low elevation to a pool or storage in the high elevation and in the peak hours, water from the high elevation pool transfer to low elevation and it causes electrical energy production peak low of power grid covering. When difference between min and max consumption is high, the daily load curve is none smooth and may be we need use saving pump power plant [3]. In this paper main purpose is feasibility of establishing a saving pump power plant for Iranian global power grid. In the [4-6], We can find operational aspects of saving pump power plants Other problems of saving pump power plant such as effect on power grid stability and voltage and other application we can utilize from [5-8] so the research on feasibility has not been investigated and it is necessary. In this paper first of all wasp briefly has been explanted, then a case study on global power grid of Iran is considered and the result of feasibility of wasp has been presented.

Mathematical modeling for generation expansion planning used in WASP

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 … 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:

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

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 j for 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.

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

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 WASP, 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 WASP.

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

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.

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

As we said one of our purposes of this feasibility study of saving pump power plant is for Iranian global power grid. In Iran the different between maximum and minimum load is very high, establishing a pump storage power plants is economical. In Iran pump storage power plants apply when the conditions are in the peak, but in addition to load providing, pump storage power plants can apply for automatic control of frequency, energy saving, supporting the renewable energy sources, the control of active and reactive power, improving the quality of power and endurances of capability, cost minimizing, install in the near location of consumer without and limitation in the location, voltage regulation, stability and improving the peak.

The implementation of WASP-IV in Iranian power grid

The input information of WASP-IV planning 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 figure 1.

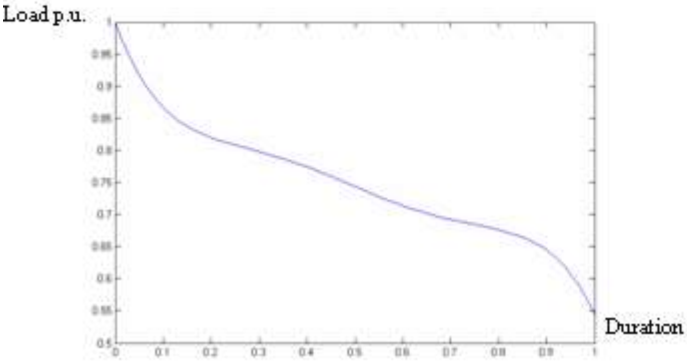

Fig. 1: Load Duration Curve for Iranian Power Grid

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.

The number of thermal power plants in Iran has been estimated to 54. 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.

Also one type of pump storage power plants has been taken as a candidate that the purpose is defining and finding the location of these power plants for Iranian global power network. Table 3 shows pumped storage power plant characteristics [3, 6, and 8].

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 donned according to cost.

Search for optimal response

When obtaining a constraint solution, the optimization results have been acquired. After final implementation of wasp, the optimal results could be visible in reprobate. In this paper the evaluation for pumped storage power plant is studied as pump storage system. To determine the capacity of candidate pumped storage power plant, three different states are considered. Pumped storage power plants with capacity of 250, 400, and 750mw have been taken in to account, then the results have been represented in table 4. Characteristics that distinguish pumped storage power plant with 250mw capacity from power plants with 400 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. 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.

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 4, 79, 47, and 3 respectively. The pump here is introduced as the candidate pumped storage power plant. The justified number of units defined by WASP is 3 for year 2020.

Conclusion

In this paper, we introduced the pump storage power plants and the overall characterization of this power plant has been presented and advantages and disadvantages of this power plant have been described. As the difference between minimum and maximum consumption increased the LDC curve would be none homogenous, so probably we need a pump storage power plant probably. In Iran the difference between minimum and maximum consumption is large and the pump storage power plant must be applied for adjusting peak in the peak conditions. In addition to adjusting peak, the pump storage power plant has many applications that we named as below: Automatic frequency control, energy storing, the supporting of renewable energy sources, the control of active and reactive power, the important of power quality and insurance capability, the minimizing coast, Installing near the consumers without limitations in location and places, voltage regulating and it's stability. In this paper we used wasp-iv software for Iranian global power grid and on the base of this program and our investigations we need three 250 mw power plant up to 2020 year.

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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 wasp 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: 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

PS* is pump storage.

Table 5: optimum solution WASP implementation

OPTIMUM SOLUTION
ANNUAL ADDITIONS: CAPACITY(MW) AND NUMBER OF UNITS OR PROJECTS
FOR DETAILS OF INDIVIDUAL UNITS OR PROJECTS SEE VARIABLE SYSTEM REPORT
SEE ALSO 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
TOTALS		30665.	3	75	47	3	3