Economic Load Dispatch of Thermal and PV system with battery storage

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ABSTRACT: *In the power system operations, the economic load dispatch of thermal generating system is among one of the most important problems.Recent global inclination towards the utilization of more and more renewable energy makes this problem important than ever. In this work, the economic dispatch of thermal and PV system with battery storage is carried out. Here Unit Commitment (UC) using Dynamic Programming (DP) approach is considered. The commitment is such that we get the total cost as minimum as possible. DP is one of the optimization techniques which give us the optimal solution. Also, the comparison of the emissions of thermal units without the PV and with the PV-battery system is presented.*

KEYWORDS: *Economic Load Dispatch, Dynamic Programming, Unit Commitment, Emissions*

I. INTRODUCTION

The Economic dispatch is the short-term determination of the optimal output of a number of power generation units, to meet the system load, at the lowest possible cost. In the US Energy Policy Act-2005 the term is defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities". To obtain the solution of the ED problem, we find the best distribution of the electrical power output from the available generating units.

Earlier to the common use of alternate sources of energy, the ED problem looked after only the conventional thermal power generators, which use non-renewable resources as fuels. Now days it has become necessary that there is a need for alternate method of generation apart from the conventional thermal energy power generation, and one of the sources that has gained popularity is the Solar-PV. Global trend of utilizing more renewable energy gave a path for the generation of electricity keeping in mind the environmental restrictions.Renewable energy sources have received a noticeable importance in researches and studies. And one of the noteworthy points is that there is no operation cost and it has positive effect on environment. Among the alternative sources that are examined for the generation of electricity are a number of unconventional sources including the solar and the wind energy. In recent decades, PV held a good position as there is no operating cost which causes a reduction in the total cost when it is integrated with the conventional system; thus PV applications became more practical for the generation of the power.

In the case of huge penetration of varying power sources such as PV, may be due to the weather conditions or the day and night phenomenon thermal units requires a serious operation pattern because as we can see the outputs from PV generators are affected by the change in the radiation of solar energy. Thus, the large scale utilization of solar energy depends on the flexible operation of the thermal units. In such a situation it is obvious that thermal units would be required to change their output faster, keeping in mind the constraints of the generator.Moreover, PV units are paired with energy storage elements like batteries, to stack up the excess power generated during off-peak hours which is given back as generation when the generation is expensive. For a system to have economic operation, the PV/Battery commitment and dispatch must be optimal.

II. UNIT COMMITMENT

In the planning and operation of power systems the unit commitment (UC) problem is mandatory. The aim of the UC problem is to correctly schedule the on-off states of all the units in the generation system. In addition to satisfying a number of generator constraints, the optimal UC should meet the estimated load demand along with the spinning reserve requirement at every time interval such that the total cost is minimum. Formulation of the UC problem is a combinatorial optimization problem with 0-1 variables which represents on-off status respectively. But, on a broader scale the combinations of 0's and 1'svariables grow exponentially. Therefore, this problem is one of the most difficult one to solve in the power systems.

Decision making is required in the thermal unit commitment to turn on/off of thermal units over a specific period. After the determination of on/off states, this problem also involves deciding the hourly thermal output power in order to meet the system load at lowest possible price.

III. PROBLEM FORMULATION

Our objective is to minimize the cost of the thermal units.

As we know that there is no operating cost for the PV system. So, the total cost will be only the cost of thermal units which is formulated as below.

$$Total\ Cost = \sum_1^N F_. ,$$
Subject to:
$$Ppv = Pb + Pu + Ps$$

Power of the PV unit is equal to the sum of the battery power (Pb), spillage power (Ps) and the power of the PV itself (Pu) synced with the thermal power to meet the system load.
The power of the PV unit depends on the radiation and is defined as follows.

$$P_{pv} = \frac{\eta_c}{K_c}(G_t; 0< \quad G_t < .$$
$$P_{pv} = \eta_c G_t; \ G_t > K_c$$

Where ₎ is the certain value of the radiation (W/M^2), ₍ is the efficiency of the PV unit and ₍ is radiation value (W/M^2).

Cost of thermal units is the cost for the system and those units have their own constraints that are given below.

$$P_g^m < \quad P_g < P_g^m$$
$$-RD \leq P_t - P_{t-1} \leq RU$$
$$\text{on/off}$$

Thermal generating units have their own minimum and maximum generation value (MW), ramp up and ramp down rates (MW/hr.) that in turn depends on the minimum up and down time. Minimum up time (^{on}) is the time for which the unit must remain in on-state before it is turned-off. Minimum down time(^{off}) is the time for which the unit must remain in off-state before it is turned-on.

IV. DYNAMIC PROGRAMMING

Firstly, Dynamic programming (DP) is a systematic procedure which systematically assesses a large number of possible outcomes or the feasible solutions in a multi-step process. For work there are 4 units which can supply the 24 hour load. So, the total number of paths to satisfy the 24 hour load curve is calculated by:

Total Paths = $(2^4 - 1)$

And a feasible path is the one which supplies the required load and meets the minimum amount of capacity of a unit each period. If there were a strict priority path then we would have the following [1]:
Priority 1 Unit
Priority 1 Unit + Priority 2 Unit
Priority 1 Unit + Priority 2 Unit + Priority 3 Unit
Priority 1 Unit + Priority 2 Unit + Priority 3 Unit + Priority 4 Unit
In the DP approach we assume the following [1]:

1. A state consists of an array of units with specified units operating and the rest off-line.
2. The start-up cost of a unit is independent of the time it has been off-line
3. There are no costs for shutting down a unit
4. There is a strict priority order and in each interval a specified minimum amount of capacity must be operating

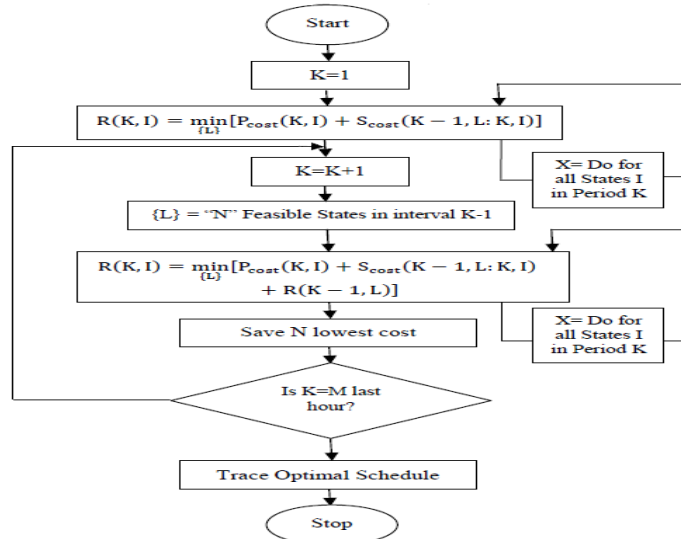Dynamic Programming algorithm can be summarized as follows [1]:

Figure 1

Where,
State (J, K) – K_{th} Combination in J_{th} hour
State (K, I) is the Ith combination in hour K.

For the forward DP approach, we define a strategy as the path from one state at a given hour to a state at the next hour.

The total cost comprises of both the production cost and the costs associated with start-up and shutdown of units. DP is a technique to solve complex problems by breaking them into simpler. The approach that we took to solve our UC problem is the forward Dynamic Program. We get minimum number of steps as much as possible. DP is the optimization technique which gives us the total cost as minimum as possible via the best feasible optimal solution.

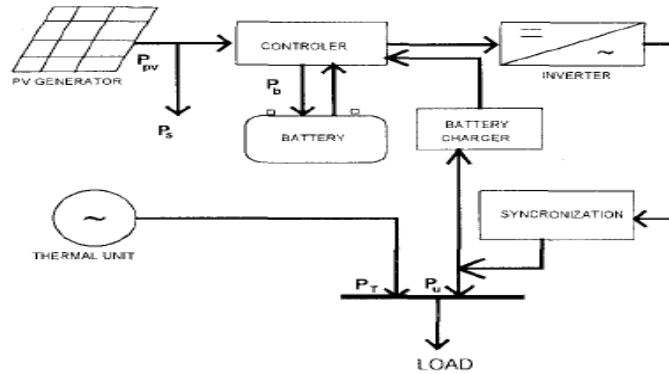## V. SCHEMATIC DIAGRAM OF THE PROPOSED SYSTEM

Figure 2

      The proposed system with the thermal units and the Photovoltaic (PV) unit with the battery system can be represented as shown above. PV generates the power proportional to the radiation. Power from the PV unit is used to charge the battery during the off-peak hours and it is discharged during the peak hours when the generation is expensive. It is the best way to store the power that can be utilized at proper time. In our system we are considering the spillage power as zero. The output of the battery and the PV unit is DC, so their power is given to the load via an inverter.
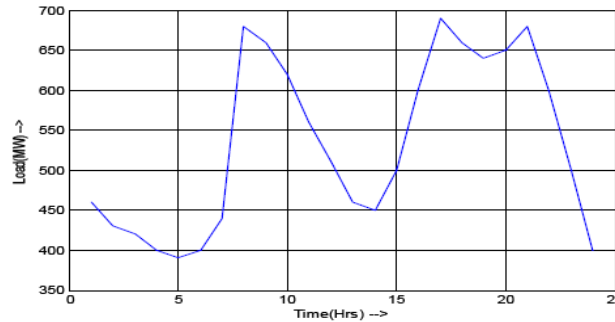
Load Curve:

Figure 3

      The daily load curve of our system is shown above. The consumer demand can never be constant at any generating station. Because, the demand of the consumer vary according to their activity. This curve is plotted with the load against the time. Also we have monthly and the yearly load curves. Monthly load curve is obtained from the daily load curve and the yearly load curve is obtained from the monthly load curve. Our daily curve shows that it has a peak value of 690 MW and minimum of about 400 MW.

Generator data:

Unit	P_{min} (MW)	P_{max} (MW)	Min Up (Hrs)	Min Dn (Hrs)	RU (MW/h)	RD (MW/h)
1	25	80	4	2	50	75
2	60	250	5	3	80	120
3	75	300	5	4	100	150
4	20	60	1	1	80	120

Table 2

In our system we are considering four thermal generators with the data as shown in the above table. The total maximum capacity of our thermal system is 690 MW.

Radiation Data:

Hour	Gt (w/m^2)	Hour	Gt (w/m^2)	Hour	Gt (w/m^2)
1	0	9	637.5	17	255
2	0	10	680	18	212.5
3	0	11	816	19	153
4	0	12	850	20	68
5	93.5	13	833	21	42.5
6	212.5	14	850	22	0
7	255	15	680	23	0
8	467.5	16	595	24	0

Table 2

Meteorological department gives the data of the radiation on the surface. It can be précised up to the interval of 5 minutes. The value of the radiation can be affected by the wind and the ambient conditions like temperature. So, we take the average hourly radiation which is shown in the table-2. It has the maximum radiation value at twelfth and the fourteenth hour. And the minimum value at twenty first hour. The output of the PV unit is proportional to the radiation. In our system we take the efficiency of the PV unit as 10% and the certain value of the radiation $K_c = 250$ w/m^2

Battery:

Generally battery is taken as a constant voltage source. The size of the battery depends on the amount of the peak load shave desired. So, the utility companies opt the battery size accordingly. Also the cost of the battery depends on the MWh capacity of the battery rather than the MW capacity. In our proposed system, battery is charged from the PV power when there is excess energy. The capacity of the battery is taken around the 60% of the maximum PV-generation. Battery capacity considered here is 50MW. We charge the battery in the twelfth hour noon time when the load reduces and the PV generation is at peak and it is discharged during the seventeenth hour when the load demand is high or in other word when the generation is expensive.

THERMAL UC:

Unit	Hours(0-24)																							
1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	*1*	1	1	1	1	1	1	0	0
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0	1	*1*	0	0	0	0	0	0	0	1	1	1	1	0	0	0	

Table 3

Unit commitment of the thermal units is shown in the above table. 1's represents the on-state of the unit and 0's represents the off state. The numbers in the italics shown in the ninth and the sixteenth hour shows that those units are turned off when we co-ordinate the thermal units with the PV-battery system.

Unit commitment of Thermal and PV system with Battery

Unit	Hours(0-24)																							
1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0

Table 4

The above table shows the UC of the thermal-PV system with battery. Apart from the ninth and the sixteenth hours in which the thermal units are not turned-off the generations of those units are reduced. Thus, helping in the cost and emission reduction.

Emissions:

Unit	e1	e2	e3	e4	e5
1	4.091	−5.554	6.490	2×10^{-4}	2.857
2,3	4.258	− 5.094	4.586	1×10^{-6}	8.000
4	5.426	−3.550	3.380	2×10^{-3}	2.000

Table 5

The above table shows the emission coefficients for the thermal units. The expression for getting the emission of a unit is given by [5]: $Em = [10^{-2}(e1 + e2P_g + e3P_g{}^2) + e4^{e5P_g}]$

Where, e1, e2..e5 are the coefficients of the units with P_g as their generated power. Emissions are calculated for each hour for every unit and the sum of the emissions is taken for all the units for twenty four hours.

VI. RESULTS

In the first case with only the thermal units the total production cost of the thermal generators we got:**£ 265,457** per day. Then in the second case where we coordinated thermal units with the PV and Battery system, the cost we got: **£ 250,576** per day. The percentage reduction in the cost is **5.605** % or **£ 14,881**per day.
Emissions: The percentage reduction in the emission when the thermal system is coordinated with the PV-battery system is **5.4054** % per day.

VII. CONCLUSION

In this work, the solution approach considered was the economic dispatch of thermal units and then the dispatch of thermal units with PV-battery system. The economic dispatch of thermal and PV system with battery storage is carried out. The Unit Commitment (UC) is done by Dynamic Programming approach. The commitment gave us the minimum possible cost. Also we have the comparison of the emissions of the thermal units when they are running with the PV-battery system and without them.

REFERENCES

[1]. A. J. WOOD, AND B. F. WALLENBERG, POWER GENERATION, OPERATION AND CONTROL, 2ND ED., NEW YORK: JOHN WILEY & SONS.
[2]. M. K. C Marwari, Haili Ma, S. M. Shahidehpour, and K. H. Abdul-
[3]. Rahman, "Short term generation scheduling in photovoltaic-utility grid
[4]. with battery storage," IEEE Trans. Power Syst., vol. 13, no. 3, pp. 1057-1062, Aug. 1998.
[5]. TomonobuSenjyu, Kai Shimabukuro, Toshihisa FunabashiMeidensha Corporation, "A Technique for Thermal and Energy StorageSystem Unit Commitment" Power Engineering Society General Meeting, 2004. IEEE-6-10 June 2004
[6]. Thermal-Electric Simulink® Model of Diesel ElectricGenerators with Economic Dispatch in Remote StandaloneSystemsR. W. Wies, Member, IEEE, L. G. Brouhard, Member, IEEE, R. A. Johnson, C-S. Lin
[7]. Ali T. Al-Awami, Member, IEEE, and Eric Sortomme, Member, IEEE "Coordinating Vehicle-to-Grid ServicesWith Energy Trading"- IEEE TRANSACTIONS ON SMART GRID, VOL. 3, NO. 1, MARCH 2012