Cost saving on the load dispatch of thermal and pv systems considering emissions

[1]Pusapati Sridevi, [2]B.Ravindranath Reddy

[1]Research Scholar, [2]Deputy Executive Engineer
Electrical & Electronics Engineering,
JNTU, Hyderabad, India

Abstract: To obtain most economical operating cost of any power system, allocation of load demand to the various generating units considering various constraints is a challenging task. Several generators are connected together in parallel and are synchronized to supply for the given load demand. In order to meet the ever-growing power demand, PV units are used in consortium with thermal units which not only decreases the cost of operation, as the solar energy is freely available, but also conserves the coal and decreases the pollution caused by emissions in thermal power plant. Hence in this paper, IEEE -30 bus system consisting of 6 thermal units are considered along with 22KW , 44KW and 66 KW rating PV (photo voltaic) units placed at various locations like Hyderabad, Kothagudem and Warangal to analyse the change in the cost of load dispatch with various combination of units. There are many Optimizing techniques, mathematical models and a number of Bio-inspired Algorithms to solve this Economic load dispatch problems. In this paper, the analysis is done at various loads using Solver- Add-in available in Excel.
The economic Load dispatch problem is solved considering fuel cost co-efficients, and losses caused due to emission for thermal units and solar irradiance at various locations for PV units and found that the cost of dispatch decreases with the increase in the number of PV units and more so if the increase in PV units in Hyderabad where the average Solar radiance over an year is high compared to the other locations

***Index Terms*:** Load Dispatch, Photo-voltaic, emission constants, valve point loading, Fuel cost coefficients, solver add-in, solar irradiance

I. INTRODUCTION

Due to ever increase in demand of electricity, it is essential to interconnect large generators in parallel to meet the load demands and also to run the units economically these generators are connected to each other through a common copper bus bar. The primary objective of multiple generating units is to make sure safe and reliable working of the power system while keeping the operating and fuel cost of generating units to the minimum level possible by timely switching of the units without affecting the load. India has a vast scope of the solar power generation due to the high solar irradiance index. The problem of economic load dispatch with the inclusion of the renewable power sources will reduce the load of generation on the thermal units and other fossil fuel units. Here in this paper we are including Photo Voltaic System (PVS) in consortium with thermal power generation units.
The load can be symmetrically divided on all the units connected in parallel, if the input output characteristic curve of all the connected thermal units is same and identical to each other, but in general this is not the case as the generators connected are of different brands, having variable efficiency, dissimilar input -output characteristics and will also have different fuel cost curves at different power outputs. It increases the need of ELD to vary the power of generating units within the desired generating limits of each individual generator considering the valve point effects and emissions(like NO_x, SO_x, CO_x etc) to meet output power demand within optimal fuel cost..
Solar PV has several features that distinguishes it from the conventional thermal generation. First, the fuel (sunlight) is free. Hence the variable costs associated with it are nearly zero. Second, increasing the level of grid-connected PV reduces operating costs, emissions (NO_x,CO_x, SO_x etc) and other pollutants. Also solar generation is variable, with predictable changes over seasons, and intermittent, with unpredictable changes in the atmosphere. They are most productive during peak loads
Economic load dispatch is conducted to compute the operating cost of Hybrid power system through the strategic dispatch of electricity while fulfilling load demand. In this paper, economic dispatch is conducted on 6 thermal units in combination with 6photovoltaic units, 2 at each location.

Solar power can be forecasted and integrated into the Grid (e.g., GE Energy, 2008). According to "A Survey of Bio inspired Optimization Algorithms 'by Binitha S, S Siva Sathya, (IJSCE, May 2012), Swarm intelligence technique is based on collective social behavior of organisms and it deals with the implementation of collective intelligence of groups of simple agents like bees, ants, krills, swarms etc as a problem solving tool. According to "Optimizing Economic Load Dispatch with Renewable Energy Sources via Differential Evolution Immunized Ant Colony Optimization Technique" by N. A. Rahmat#, N. F. A. Aziz et al(2017), (ELD) is computed to analyse the operating cost of 7Thermal power integrated to 2PV power system and could arrive at a conclusion that by integrating Thermal with PV units decreases the cost of operation as well as the losses. In this paper 6 thermal units are integrated with 6 PVunits at various locations for 1000MW load, 1200MW and 1400 MW load load separately and the cost of load dispatch is solved using solver add-in available in Excel and the results are compared. For what-if analysis and to find an optimal (maximum or minimum) value for a formula in the objective cell in Excel, **Solver** an **add**-in program can be used — subject to constraints, or limits, on the values of other formula cells on any worksheet.

2. **METHODOLOGY:** Economic Load Dispatch of Thermal Units interconnected with Solar(PV) Units:

A strategic Load dispatch is conducted to find out the most economic operating cost of the power system considering the various constraints while fulfilling load demand. For thermal power units the real power generated , the valve point loading effects and losses due to emissions are considered while for PV units the non-dispatchability with predictable changes of solar irradiance over diurnal and seasonal cycles are considered for solving ELD.

A.Operating Cost equation of Thermal power plant

The equivalent cost of the generator includes mainly the fuel cost, labour cost and maintenance cost etc. The cost depends on the requirement of output power
The quadratic fuel cost function can be given as:

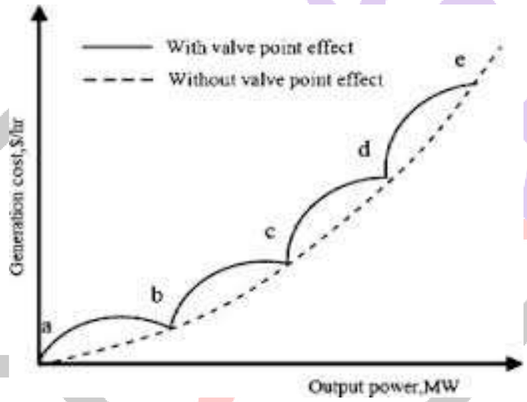
$$Cost_{gen} = \sum_{i=1}^{n} C_i\, P_i = \sum_{i=1}^{n} a_i\, P_i^2 + b_i\, P_i + c_i \qquad (1)$$

Where *Ci* is the fuel cost of generating *Pi* amount of output power. *ai*, *bi* and *ci* are the fuel cost coefficient for *Pi*.
ai = coefficient that measures of losses in the ith generator.
bi = coefficient that represents the fuel cost in the ith generator.
ci = coefficient includes salary and wages, interest and depreciation of the ith generators.

To increase the efficiency of power plants, the generators' engines are designed with valves where the control of the opening of the valves depending on the power demand is made possible. Considering the effect of valve point loading, which produces rippling effect because of variation in speed of the turbine, which inturn effects its cost,

$$Cost_{gen} = \sum_{i=1}^{n} C_i\, P_i = \sum_{i=1}^{n} a_i\, P_i^2 + b_i\, P_i + c_i + \left| d_i \sin\left(e_i\left(p_i^{min} - p_i\right)\right) \right| \qquad (2)$$

Where d_i and e_i are the coeffients reflecting valve point loading of ith generator.



The losses in the transmission network can be calculated using the formula

$$P_{loss} = \sum_i^n \sum_j^n P_i\, B_{ij}\, P_j + \sum_i^n B_{0i}\, P_i + B_{00} \qquad (3)$$

Where B_{ij}, B_{0i}, and B_{00} are the elements of loss coefficient matrix.

The total Real power to be generated is given by Real power Loss constraint

$$P_{T\,total} = \sum_{i=1}^{N_g} P_i = P_D + P_{loss} \qquad (4)$$

The total generated power by Thermal units must be equal to the summation of load demand, P_D and power loss, P_{loss} as in Eq. (4)

The inequality constraint of generation limits for each unit is given by Eq.(5)

$$P_{imin} \le P_i \le P_{imax} \qquad (5)$$

Where *Pimin* and *Pimax* is the minimum and maximum generation limits of i[th] generator respectively.

Ramp Rate Limit constraint of the generating unit is given by for increase in generation, $P_i - P_i^o \le UR_i$ **(6)**

for decrease in generation, $P_i - P_i^o \ge DR_i$ **(7)**

where P_i is the current output power, P_i^o is the previous output power, UR_i , DR_i are the upramp limit and down ramp limit of the i th generator in MW/ time period.

The emission dispatch involves generation of required power for serving the system load with minimum emissions in the form of COX, SOX and NOX to the atmosphere
The emission dispatch function for a particular power generation is give by

$$Emission\ Cost = \sum_{i=1}^{n} \alpha_i\ P_i^2 + \beta_i\ P_i + \gamma_i \quad \textbf{(7)}$$

Where αi, βi, γi are coefficient of emission of the ith generating unit

The Objective function considering valve point loading and emission is given as

$$\text{Min}(Cost_{gen}) = Min\ (\sum_{i=1}^{n}((a_i\ P_i^2 + b_i\ P_i + c_i + \left| d_i\ \sin(e_i\ (p_i^{min} - p_i)\right| + h_i(\alpha_i P_i^2 + \beta_i P_i + \gamma_i))) \quad \textbf{(8)}$$

$$\text{Where } h_i = \frac{a_i\ P_{imax}^2 + b_i P_{i\,max} + c_i}{\alpha_i P_{imax}^2 + \beta_i P_{imax} + \gamma_i} \quad \textbf{(10)}$$

Where P_{imax} is the maximum generation limit of i^{th} generator
h_i is the price penalty function for emissions for i^{th} generator.

B. The operating cost of each PV unit is given by

Considering the placement of 22KW ,44 KW & 66KW PV units in the regions of Hyderabad(17.35^0 N, 78.45^{0}E), Warangal (17.95^{0}N, 79.65^{0}E), Kothagudem (17.55^{0}N, 80.65^{0}E), the average output power of the units is calculated based on the solar radiance values of every month [9].

The expected solar output power of i th unit is given by

$$P(PV_i) = P(PV_{io}) * f_b(S_i) \quad (11)$$

Where $f_b(S_i)$ is the beta distribution function to find the distribution of solar radiance across the panel.
PV_{io} is the power generation of panel

$$PV_{io} = N * FF * V_y I_y \quad (12)$$

where N is the total number of PV modules.
FF is the fill factor
V_y and I_y are calculated from the open circuit and short circuit characteristics of PV cell at ambient temperatures.

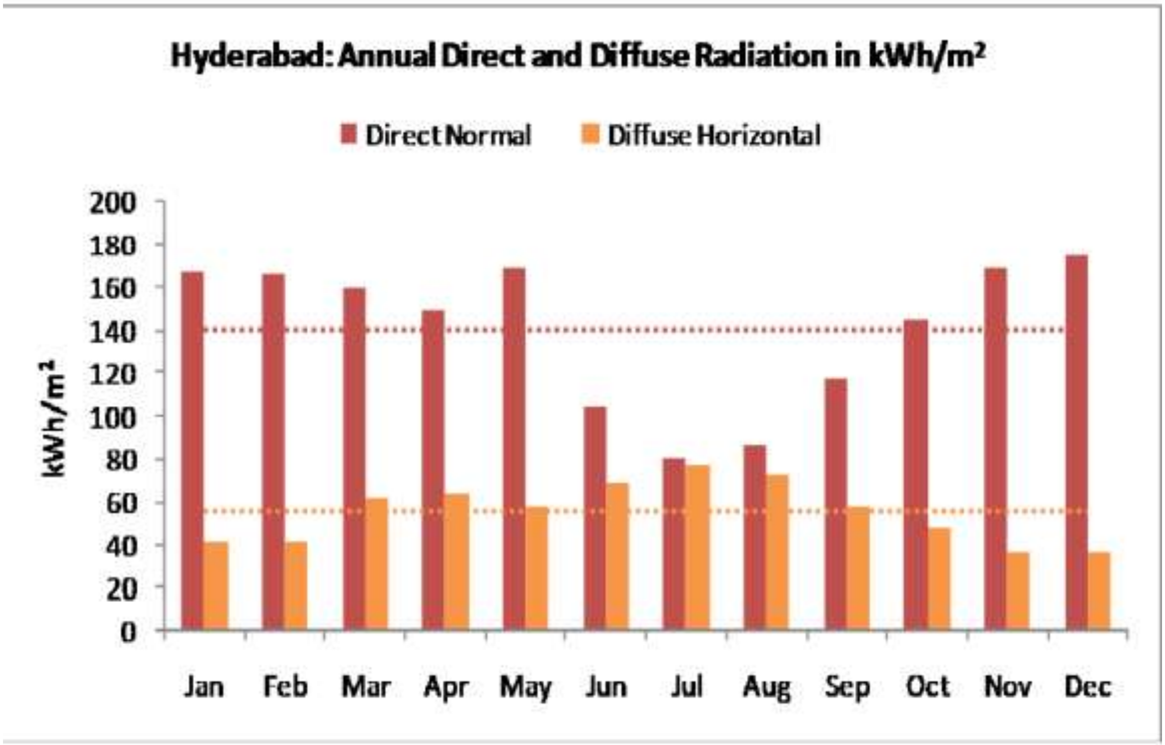


Chart1: Solar radiation at Hyderabad along the year

The objective function of this study is to minimize the operating cost of power system when PV units are used along with Thermal units for Economic distribution of load among the units.
The total operating cost of conventional generators and PV units is calculated by combining Eq. (1) and eq. (5),

$$\textbf{Cost}_{\text{total}} = \sum_{i=1}^{n}(C_i P_i) + \sum_{i=1}^{m} cost(PV_{ij}) \quad (12)$$

The Equation (6) is evaluated considering the fuel co-efficients, emission co-efficients and minimum and maximum loading capacities for thermal units and average capacities based on solar irradiance values of Solar PV units.

3. Results and Discussions

Fuel cost coefficients, Emission co-efficients and capacities of IEEE-30 bus system with thermal units is given in Table1, and The Value of Penalty factor for emissions at various loads are calculated as per equation (10) and given in Table 2. PV Watt calculation based on solar radiance data as given by NREL at various locations is given in Table 3 [9]. The cost of dispatch of 1000 MW load ,1200 MW and 1400MW loads is calculated using Solver Add in tool for finding optimum (minimum) value of cost while using 6 Thermal units alone and 6 Thermal units linked with 6 PV units placed at various locations is given in Table 4. Also the cost of dispatch of 1000MW load on 6 Thermal units interlinking with 2 PV units of 22KW rating panels & 44KW rating panels of 1000 each placed at Hyderabad, Warangal & Kothagudem is given in Table 5. The % cost saving at various loads on connecting PV units to the grid is given in Table 6.
It is observed that the cost of dispatch decreases with the increase in the number of PV units and more so if the increase in PV units in Hyderabad where the solar radiance is high compared to the other locations.

Table1: Fuel cost coefficients, Emission co-efficients and capacities of IEEE-30 bus system

Thermal Unit	**Fuel cost co-efficients**			**P G min**	**P G max**	αi (Kg/MW2hr)	βi (Kg/MWhr)	γ_i (Kg/hr)
	a	**b**	**C**	**MW**	**MW**			
Th.G1	0.15247	38.539	756.79	10	125	0.00419	0.3267	13.85932
Th.G2	0.10587	46.159	451.32	10	150	0.00419	0.3267	13.85932
Th.G3	0.02803	40.396	1049.99	35	225	0.00683	-0.54551	40.2669
Th.G4	0.03546	38.305	1243.53	35	210	0.00683	-0.54551	40.2669
Th.G5	0.02111	36.327	1658.56	130	325	0.00461	-0.51116	42.89553
Th.G6	0.01799	38.27	1356.65	125	315	0.00461	-0.51116	49.89553

Table2: Value of Penalty factor for emissions at various loads

Load	hi (penality factor)
1000	47.82
1200	62.04
1400	66.25

Table : 3 PV Watt calculation based on solar radiance data

S.No.	Location	Specifications	Season	22KW	44KW	66KW
1	Hyderabad	17.35° N, 78.45° E	Summer	15.817	31.635	47.451
			Monsoon	14.476	28.95	43.428
			Winter	16.567	33.136	49.701
			Average	15.62	31.24	46.86
2	Warangal	17.95° N, 79.65° E	Summer	15.534	31.07	46.602
			Monsoon	13.987	27.974	41.961
			Winter	16.297	32.583	48.891
			Average	15.273	31.07	45.819
3	Kothagudem	17.55° N,80.65° E	Summer	15.432	30.865	46.296
			Monsoon	13.504	27.009	40.512
			Winter	15.685	31.37	47.055
			Average	14.874	29.748	44.622

Table 4: Load dispatch and its cost at various loads with & without PV

Rating	1000MW				1200MW				1400MW			
Unit	without PV		With PV		without PV		With PV		without PV		With PV	
	Load	cost	Load	cost	Load	cost	Load	cost	Load	cost	Load	cost
Th.G1	102.884	10726.769	83.360	8386.339	125.000	15411.581	117.798	14266.816	125.000	15916.276	125.000	15916.276
Th.G2	106.094	11115.779	83.607	8420.108	148.403	19225.683	122.388	14920.643	150.000	20166.154	144.559	19182.795
Th.G3	158.486	14151.303	139.129	11831.179	186.438	20472.727	165.373	16986.611	225.000	28998.829	181.491	20316.214
Th.G4	158.122	14153.896	139.208	11886.572	185.698	20404.950	164.974	16975.248	210.000	25882.070	180.862	20262.475
Th.G5	237.688	20181.402	209.345	16784.063	277.405	29233.470	246.417	24105.310	325.000	39786.052	269.827	28935.414
Th.G6	236.726	20377.624	208.049	16939.909	277.055	29603.584	245.750	24422.887	315.000	38136.159	269.425	29322.583
PV H 22			15.620	62.480			15.620	62.480			46.860	187.440
PV W 22			15.273	61.092			15.273	61.092			45.819	183.276
PV KG 22			14.874	59.496			14.874	59.496			44.622	178.488
PV H 44			31.240	124.960			31.240	124.960			31.240	124.960
PV W 44			30.546	122.184			30.546	122.184			30.546	122.184
PV KG 44			29.748	118.992			29.748	118.992			29.748	118.992
Total	**1000**	**90706.8**	**1000**	**74797.4**	**1200**	**134352**	**1200**	**112227**	**1350**	**168886**	**1400**	**134851**

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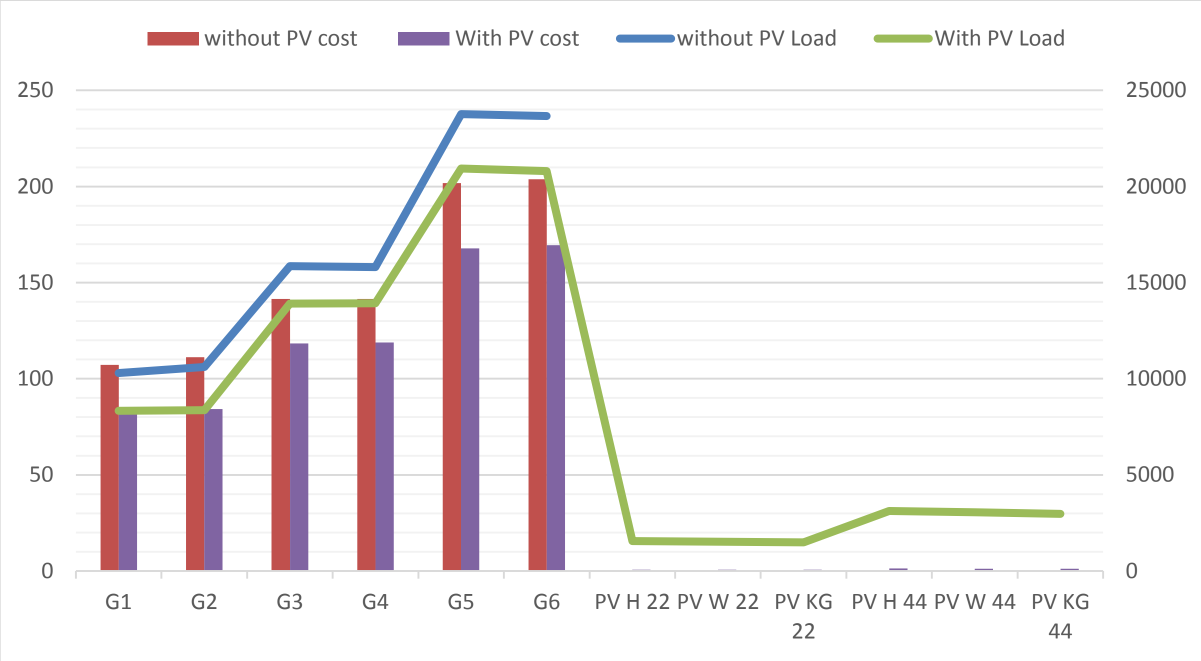

Chart 2: Cost Vs Load chart with and without PV

Table 5: Load dispatch and its Cost for 1000MW with 2 PV units at various locations

Location	Hyderabad		Warangal		Kothagudem	
Unit	Load	cost	load	cost	load	cost
Th.G1	96.20201	9895.45	96.34967	9913.479	96.51891	9934.163
Th.G2	98.40013	10158.56	98.56501	10178.7	98.76525	10203.17
Th.G3	151.8989	13331.91	152.035	13348.52	152.2144	13370.44
Th.G4	151.6696	13351.25	151.8122	13368.66	151.9785	13388.99
Th.G5	228.03	18980.15	228.2809	19010.79	228.493	19036.71
Th.G6	226.9393	19160.41	227.1382	19184.69	227.4079	19217.65
PV 22	15.62	62.48	15.273	61.092	14.874	59.496
PV 44	31.24	124.96	30.546	122.184	29.748	118.992
Total	**1000**	**85065.2**	**1000**	**85188.1**	**1000**	**85329.6**

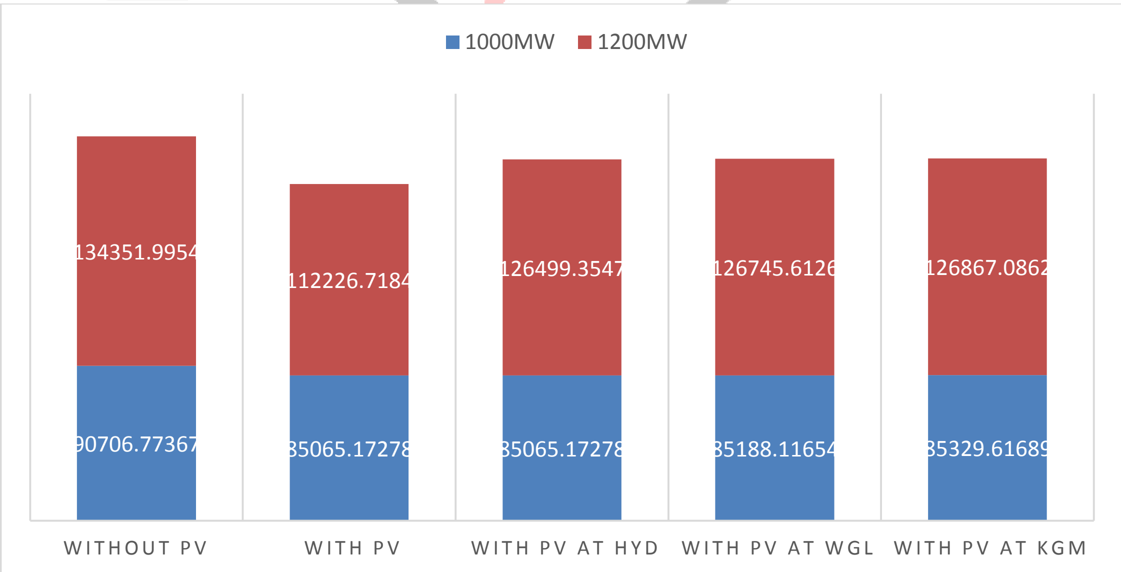

Chart 3 : Cost comparison chart for 1000MW & 1200KW at various locations.

Table 6 : Cost comparison Table

Units/Load	1000MW	1200MW	1400MW
Without PV	90706.8	134352	168886
With PV	74797.4	112227	134851
% cost saving	**17.5393**	**16.4681**	**20.15241**

Conclusion: It is found from the above tables & charts that as the number of PV units are added to thermal units at various loads, the cost of dispatch is reduced. Hence it is required to find out the optimum PV units to be interconnected at various locations to Thermal units in order to obtain most economical Load dispatch.

Scope of Work: The ELD can be solved by considering the parameters like prohibited operating zone, ramp-rates, and valve-point loading effect on thermal power generators to get more appropriate values of cost saving.

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