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Analysis of active power load dispatch in economic and environmental aspects with pseudo power flow

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ABSTRACT:

In this paper a methodology with Pseudo power load flow implementation has been presented to remove extra burden on slack bus in both economic and environmental aspects. Using this methodology, the effect of nature of power plant (Thermal/Gas) has been analyzed on the generation cost, emission and power loss distribution. This work can be applied to any system as it is not dependent on type as well as the nature of system. The complete methodology has been tested on IEEE-30 bus test system with supporting numerical and graphical results.

Index Terms: *economic, emission, slack bus, power flow, economic dispatch.*

1.INTRODUCTION:

In the past few decades, the demand for electricity has been increasing drastically day-by-day. This needs to operate and control the power system effectively. The conventional load flow solution methods such as Gauss Siedal, Newton-Raphson, Decoupled, Fast decoupled, etc suffers from solving the realistic system conditions such as wide angle voltage profiles. Similarly, the total power losses are allocated to slack bus which increases the burden on slack generator. These methods work independent of the system objectives hence it is very difficult to obtain optimized cost and emission values. By considering all these aspects, in this work, a Pseudo load flow solution technique based on approximated power flow equations are formulated using truncated taylor series expansion. Similarly, loss distribution algorithm based on participation factors is developed to distribute losses to all generators to minimize burden on slack generator.

The literature highlights, power flow analysis is one of the most essential part of analysis of power system [1-6]. In conventional power flow analysis main drawbacks are one is unrealistic allocation of losses to slack bus only but practically it is not feasible in the power system operation [7]. Other one is violation of equal incremental cost criteria for slack bus. Such case arises due to slack generation which is obtained after the power flow solution. Thus researchers have concentrated in removing the burden on slack bus by distributing loss to all the remaining generators while satisfying equal incremental cost criteria in economic load dispatch problems. Economic and environmental dispatch problems are solved using different methods.

The literature [8,9] presents a methodology to distribution of generation based on the frequency deviation. This method works based on automatic generation control using frequency characteristics. In [10], another technique based on NR load flow method is presented. In this method, loss term is introduced. In [11-13], the slack burden is removed in consideration with losses in economic aspect is presented.

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However, these methods suffer from the highest computational calculations and increased mathematical complexity.

From the literature, it is noted that, the burden on slack bus can be removed with a sense of economic aspect. As the generator has both economic and emission characteristics, approximated using quadratic curve. Hence it is motivated that, the burden on slack bus can be released not only in economic aspect but also in emission aspect also. In this chapter, a new methodology to remove burden on slack bus in emission aspect in Pseudo load flow formulation is presented. The comparative analysis for economic and emission aspects is presented.

2. PSEUDO POWER FLOW PROBLEM FORMULATION

The conventional AC load flow equations in polar form can be written as:

$$P_k = \sum_k V_k V_m Y_{km} \cos(\theta_{km} + \delta_m - \delta_k)$$

$$Q_k = -\sum_k V_k V_m Y_{km} \sin(\theta_{km} + \delta_m - \delta_k)$$

By approximating trigonometric functions using truncated Taylors series approximations

$$\sin(\delta_k - \delta_m) \cong (\delta_k - \delta_m)$$

$$\cos(\delta_k - \delta_m) \cong 1$$

Using Eqns (3.1) and (3.2), the load flow equations in expanded form can be written as

$$P_k = \sum_k V_k V_m Y_{km} \left(\cos\theta_{km} . \cos(\delta_k - \delta_m) + \sin\theta_{km} (\delta_k - \delta_m)\right)$$

$$Q_k = -\sum_k V_k V_m Y_{km} \left(\sin\theta_{km} \cos(\delta_k - \delta_m) - \cos\theta_{km} \sin(\delta_k - \delta_m)\right)$$

By applying trigonometric approximations, the Pseudo power injections at bus-k are

$$P_k = \sum_k V_k V_m Y_{km} \left(\cos\theta_{km} + \sin\theta_{km} (\delta_k - \delta_m)\right)$$

$$Q_k = -\sum_k V_k V_m Y_{km} \left(\sin\theta_{km} - \cos\theta_{km} (\delta_k - \delta_m)\right)$$

Similarly, Pseudo power injections at bus-m are

$$P_m = \sum_k V_k V_m Y_{km} \left(\cos\theta_{km} - \sin\theta_{mk} (\delta_k - \delta_m)\right)$$

$$Q_m = -\sum_k V_k V_m Y_{km} \left(\sin\theta_{km} + \cos\theta_{mk} (\delta_k - \delta_m)\right)$$

3. LOSS DISTRIBUTION METHODOLOGY

3.1Modeling in economic aspects:

The objective function is to minimize the overall cost of production of power generation. Let us consider is the total number of units in the system (‘NG’) and cost of power generation (‘$C_i(P_{Gi})$’) of unit-i, which is given for each plant. The total generation fuel cost objective function is defined as

$$FC = \sum_{i=1}^{NG} C_i(P_{Gi}) = \sum_{i=1}^{NG} \left(a_i P_{Gi}^2 + b_i P_{Gi} + c_i\right) \qquad \$/h$$

Where, α_i, b_i, c_i are the fuel cost coefficients of i^{th} unit.

The economic power system operation needs to satisfy the following equality constraint

Without losses: $\sum_{i=1}^{NG} P_{G_i} - P_D = 0$; With losses: $\sum_{i=1}^{NG} P_{G_i} - P_D - P_L = 0$

By considering the above constrained optimization problem along with the equality constraint can be solved by using the Lagrangian multiplier (λ). Then, the augmented fuel cost function becomes,

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$$\text{minimisation of}\left(FC'\right) = \left[FC - \lambda\left[\sum_{i=1}^{NG} P_{Gi} - P_D\right]\right]$$

The condition for optimality of this augmented function is

$$\frac{\partial FC_1}{\partial P_{G1}} = \frac{\partial FC_2}{\partial P_{G2}} = \frac{\partial FC_3}{\partial P_{G3}} = \lambda$$

After solving Eqn (4.5) using Eqn (4.4), we get the necessary conditions for optimal dispatch when losses are neglected is as follows:

$$\frac{\partial FC_i}{\partial P_{Gi}} \begin{cases} = \lambda & ; \text{ for } P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}; & \forall i = 1,2,3,\ldots, NG \\ \le \lambda & ; \text{ for } P_{Gi} = P_{Gi}^{max} & ; \quad \forall i = 1,2,3,\ldots, NG \\ \ge \lambda & ; \text{ for } P_{Gi} = P_{Gi}^{min} & ; \quad \forall i = 1,2,3,\ldots, NG \end{cases}$$

After solving Eqn.(4.6) using Eqn.(4.2), we get

$$b_i + 2a_i P_{Gi} = \lambda$$

From this condition,

$$P_{Gi} = \frac{\lambda - b_i}{2a_i}$$

By applying summation on both sides for all generators,

$$\sum_{i=1}^{NG} P_{G_i} = \sum_{i=1}^{NG} \frac{\lambda - b_i}{2a_i}$$

$$\lambda = \frac{\sum_{i=1}^{NG} \frac{b_i}{2a_i} + \sum_{i=1}^{NG} P_{G_i}}{\sum_{i=1}^{NG} \frac{1}{2a_i}}$$

To remove extra burden on slack bus, the P_{Gi} including power losses can be calculated as

$$P_{G_i} = \frac{-b_i}{2a_i} + \frac{\sum_{i=1}^{NG} \frac{b_i}{2a_i}}{2a_i \sum_{i=1}^{NG} \frac{1}{2a_i}} + \frac{P_D}{2a_i \sum_{i=1}^{NG} \frac{1}{2a_i}} + \frac{P_L}{2a_i \sum_{i=1}^{NG} \frac{1}{2a_i}}$$

In Eqn.(4.10), the first three terms refers to scheduled generation, hence, the new generation becomes

$$P_{G_i}(\text{new}) = P_{G_i}(\text{scheduled}) + \left(\frac{1}{2a_i \sum_{i=1}^{NG} \frac{1}{2a_i}}\right) \times P_L$$

$$P_{G_i}(\text{new}) = P_{G_i}(\text{scheduled}) + P_L \times LCF_i$$

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Where $LCF_i = \left(\dfrac{1}{2a_i \sum_{i=1}^{NG} \dfrac{1}{2a_i}} \right)$ is called as Loss Contribution Factor for cost minimization criteria.

In this process $P_{G_i}(new)$ is rescheduled accordingly based on the respective minimum and maximum generation limits. For example if $P_{G_i}(new)$ violates P_{Gi}^{min}, $P_{G_i}(new)$ fixed at minimum and the remaining generators are rescheduled using load dispatch.

3.2Modeling in emission aspects:

The total emission objective function is defined as

$$EC = \sum_{i=1}^{NG} E_i(P_{Gi}) = \sum_{i=1}^{NG} \xi r_i\left(\alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2\right) ton/h$$

Where, α_i, β_i, γ_i, ξ_i, r_i are the emission coefficients of i^{th} unit.

The environmental concern of power system operation needs to satisfy the following equality constraint

$$\text{Without losses: } \sum_{i=1}^{NG} P_{G_i} - P_D = 0\text{; With losses: } \sum_{i=1}^{NG} P_{G_i} - P_D - P_L = 0$$

By considering the above constrained optimization problem along with the equality constraint can be solved by using the Lagrangian multiplier (λ). Then, the augmented emission function becomes,

$$\text{minimisation of } \left(EC'\right) = \left[EC - \lambda\left[\sum_{i=1}^{NG} P_{Gi} - P_D\right]\right]$$

The condition for optimality of this augmented function is

$$\frac{\partial EC_1}{\partial P_{G1}} = \frac{\partial EC_2}{\partial P_{G2}} = \frac{\partial EC_3}{\partial P_{G3}} = \lambda$$

After solving Eqn (4.24) using Eqn (4.23), we get the necessary conditions for optimal dispatch when losses are neglected is as follows:

$$\frac{\partial EC_i}{\partial P_{Gi}} \begin{cases} = \lambda \quad ; \quad \text{for } P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}; \quad \forall i = 1,2,3,K,NG \\ \le \lambda \quad ; \quad \text{for } P_{Gi} = P_{Gi}^{max} \quad ; \quad \forall i = 1,2,3,K,NG \\ \ge \lambda \quad ; \quad \text{for } P_{Gi} = P_{Gi}^{min} \quad ; \quad \forall i = 1,2,3,K,NG \end{cases}$$

After solving Eqn.(4.25) using Eqn.(4.21), we get

$$\xi r_i (2\gamma_i P_{G_i} + \beta_i) = \lambda$$

By applying summation on both sides for all generators,

$$\sum_{i=1}^{NG} P_{G_i} = \sum_{i=1}^{NG} \frac{\lambda - \xi r_i \beta_i}{2\xi r_i \gamma_i}$$

$$\lambda = \frac{\sum_{i=1}^{NG} \dfrac{\xi r_i \beta_i}{2\xi r_i \gamma_i} + \sum_{i=1}^{NG} P_{G_i}}{\sum_{i=1}^{NG} \dfrac{1}{2\xi r_i \gamma_i}}$$

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To remove extra burden on slack bus, the P_{Gi} including power losses can be calculated as

$$P_{G_i} = \frac{-\xi r_i \beta_i}{2\xi r_i \gamma_i} + \frac{\sum_{i=1}^{NG} \frac{\xi r_i \beta_i}{2\gamma_i}}{2\xi r_i \gamma_i \sum_{i=1}^{NG} \frac{1}{2\xi r_i \gamma_i}} + \frac{P_D}{2\xi r_i \gamma_i \sum_{i=1}^{NG} \frac{1}{2\xi r_i \gamma_i}} + \frac{P_L}{2\xi r_i \gamma_i \sum_{i=1}^{NG} \frac{1}{2\xi r_i \gamma_i}}$$

In Eqn.(4.29), the first three terms refers to scheduled generation, hence, the new generation becomes

$$P_{G_i}(\text{new}) = P_{G_i}(\text{scheduled}) + \left(\frac{1}{2\xi r_i \gamma_i \sum_{i=1}^{NG} \frac{1}{2\xi r_i \gamma_i}} \right) \times P_L$$

$$P_{G_i}(\text{new}) = P_{G_i}(\text{scheduled}) + P_L \times LCF_i$$

Where $LCF_i = \left(\frac{1}{2\xi r_i \gamma_i \sum_{i=1}^{NG} \frac{1}{2\xi r_i \gamma_i}} \right)$ is called as Loss Contribution Factor for emission minimization criteria.

4. PROCEDURE FOR THE IMPLEMENTATION OF PROPOSED METHODOLOGY

The flow chart for the modified load dispatch problem in economic and environmental aspects is shown in Fig.1.

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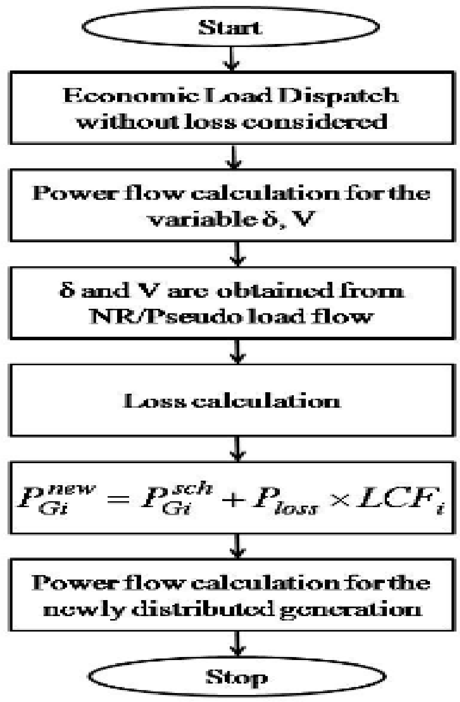

Fig.1 Flow chart for the modified ELD problem

5. RESULTS AND ANALYSIS

To show effectiveness of environmental aspects for loss distribution algorithm with load flow formulation, IEEE 30 bus test system is considered.

For IEEE-30 bus system, the generator fuel cost coefficients and the fuel emission coefficients are given in Tables. A1and A2. The results for the generations in economic and emission aspects have been compared and tabulated in Table.4.1, 4.2 and 4.3. From these tables, it is identified that, the generations are rescheduled to minimize the respective objectives. It is also observed that, while minimizing one of the objectives, the value of the other objective is increased. For example, while minimizing the generation fuel cost, the value of the emission is increased, this in turn increases the total generation and there by the total power loss and vice-versa. The variation of generations in economic and emission aspects for without and with slack distribution is shown in Fig.2. From this figure, it is observed that, with loss distribution, the generation value of generators is increased when compared to without loss distribution. Similarly, the variation of generations without and with loss distribution in economic and emission aspects is shown in Fig.3.

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Table.1 Loss distribution based generations in environmental aspect for IEEE-30 bus system

	Gen. Bus No	Emission aspect		
		ELD without loss	Pseudo LF without loss distribution	Pseudo LF with loss distribution
P_{GSCH} (MW)	1	32.76854	36.70255	33.61062
	2	61.58752	61.58752	61.99426
	5	32.76854	32.76854	33.67313
	8	61.58752	61.58752	61.99426
	11	32.03187	32.03187	32.93646
	13	62.65602	62.65602	63.06277
	Total Generation in (MW)	283.4	287.334	287.2715
	Generation Cost ($/h)	969.2422	980.8889	982.6409
	Emission (ton/h)	577.8738	595.1564	594.3281
	P_L (MW)	5.68E-14	3.934013	3.871497

Table.2 Loss distribution based generations in economic aspect for IEEE-30 bus system

	Gen. Bus No	Economic aspect		
		ELD without loss	Pseudo LF without loss distribution	Pseudo LF with loss distribution
P_{GSCH} (MW)	1	93.66297	97.10139	94.36502
	2	9.141025	9.141025	9.496527
	5	93.66297	93.66297	94.45361
	8	9.141025	9.141025	9.496527
	11	53.66297	53.66297	54.45361
	13	24.12903	24.12903	24.48454
	Total Generation (MW)	283.4	286.8384	286.7498
	Generation Cost ($/h)	881.4167	893.1601	893.126
	Emission (ton/h)	1325.67	1367.842	1351.303
	P_L (MW)	-2.8E-13	3.438417	3.34983

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Table.3 Comparison of loss distribution based generations in economic and environmental aspects for IEEE-30 bus system

	Gen. Bus No	Pseudo LF with loss distribution	
		Economic aspect	Emission aspect
P_{GSCH}	1	94.36502	33.61062
	2	9.496527	61.99426
	5	94.45361	33.67313
	8	9.496527	61.99426
	11	54.45361	32.93646
	13	24.48454	63.06277
	Total Generation (MW)	286.7498	287.2715
	Generation Cost ($/h)	893.126	982.6409
	Emission (ton/h)	1351.303	594.3281
	P_L (MW)	3.34983	3.871497

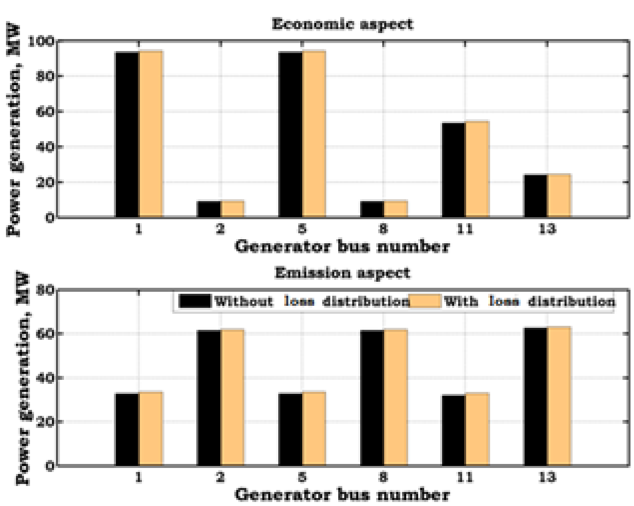

Fig.2 Variation of generations in economic and emission aspects without for IEEE-30 bus system

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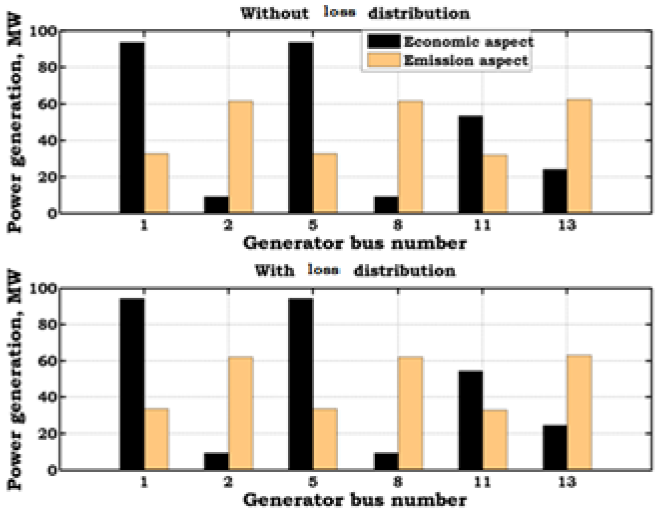

Fig.3 Variation of generations without and with loss distribution in economic and emission aspects for IEEE-30 bus system

6. CONCLUSION

A methodology has been presented to remove extra burden on slack bus in both economic and emission aspects. Using this methodology, the effect of nature of power plant (Thermal/Gas) has been analyzed on the system objectives. From the analysis, it has been identified, in economic aspect, the Thermal generators have increased their generation where as gas generators have decreased, and in emission aspect the gas generators have increased their generation where as thermal generators have decreased. Using loss distribution algorithm, the loss has been distributed to generators in an IEEE 30 bus system based on the cost and emission coefficients..

APPENDIX

Table.A1 Generator fuel cost coefficients for IEEE-30 bus system

Generator Bus No	a ($/MW²-h)	b ($/MW-h)	c ($/h)	Nature of plant
1	0.00375	2.7	0	Thermal
2	0.00834	3.25	0	Gas
5	0.00375	2.7	0	Thermal
8	0.00834	3.25	0	Gas
11	0.00375	3	0	Thermal
13	0.00834	3	0	Thermal

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Table.A2 Generator fuel emission coefficients for IEEE-30 bus system

Generator Bus No	α (ton/MW²-h)	β (ton/MW-h)	γ (ton/h)	Nature of plant
1	0.0649	-0.11554	0.04091	Thermal
2	0.0338	-0.0255	0.05326	Gas
5	0.0649	-0.11554	0.04091	Thermal
8	0.0338	-0.0255	0.05326	Gas
11	0.0649	-0.01992	0.04091	Thermal
13	0.0338	-0.097731	0.05326	Thermal

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