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A Methodology to Substitute Slack bus under Wide Angle Starting Points using Pseudo Load Flow Formulation

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Abstract: Modern power system is very complex and interconnected. The losses that occur in the power system were assigned to slack bus and an equal incremental cost cannot be maintained in Economic Load Dispatch (ELD) problem. In order to overcome this problem, in this paper, a modified power flow analysis by using economic load dispatch is developed. In this method, an additional factor is introduced. Using this, the losses assigned to slack bus are distributed to remaining generator buses so that the equal incremental fuel cost can be maintained in ELD problem. But, there are some cases where the conventional Newton-Raphson (NR) load flow problems failed to converge. In such cases, by using some truncated Taylor series approximations, the pseudo flow equations are developed to obtain the solution. These equations provide a robust starting process for the NR solution of the conventional load flow problem. A methodology to solve more realistic system with wide voltage angles, Pseudo load flow equations is developed. The effectiveness of the developed methodology in obtaining optimal schedules for the generators to solve ELD problem using the conventional NR and developed Pseudo load flow formulations are planned to verify on IEEE-9 bus test system with supporting numerical and as well as graphical results.

Keywords: Economic load dispatch; Pseudo load flow formulation; Removal of slack bus; Load flow approximations.

I. INTRODUCTION

Power flow studies are one of the most important aspects of power system planning and operation. It gives sinusoidal steady state solution of the entire system voltages; real and reactive power generated and absorbed and line losses. Several conventional methods are used for load flow analysis such as Gauss method, Gauss Siedal method, Newton-Raphson method, Decoupled and Fast Decoupled methods, etc.

The planning and operation of power systems are becoming increasingly complex. Systems are more interconnected and operating closer to their performance limits [1]. As a result, maintaining system security and facilitating efficient system operation have been challenging tasks. Most of the time the power system operates normally and the operator's job are not stressful. Under emergency conditions, the operator must quickly absorb and sort through a large amount of data and take corrective action. In these highly stressful situations, the results of errors can be severe-including large-scale blackouts and damage to expensive capital equipment. Power System Designers need a better understanding of actual grid operations, as well as the capability to examine the days when there were operational problems [2].

Transmission plays a key role in the power system operation. Transmission can function as a pipeline or as a bottleneck. Unless something is done to reduce congestion or increase transmission capacity, there is always the possibility of more blackouts. Most solutions proposed in the literature to alleviate this problem concentrate on rescheduling the power flow using some kind of economic incentives or economic penalty approaches [3, 4]. In recent years, greater demands have been placed on the transmission network, and these demands will continue to increase because of the increasing number of non-utility generators and heightened competition among the utilities themselves. Increased demands on transmission, absence of long term planning, and the need to provide open access to generating companies and customers, all together have created tendencies toward less security and reduced quality of supply.

The power flow analysis is the essential and fundamental tool to power system engineers. However the conventional power flow analysis has least two drawbacks due to the existence of the slack bus and not maintaining the equal incremental fuel cost characteristics. Moreover the electricity market is more and more deregulated, the idea that some specified groups of generators play the role in slack bus looks inappropriate. The technique of removing the concentrated burden of the slack bus is considered in the way of distributing all losses to each generator bus in a power system. Up to now, several studies have attempted to find and develop this kind of distribution technique. The distribution technique based on the frequency deviation is developed in [5, 6]. Another technique where a loss term

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is introduced to Newton-Raphson (NR) formulation is presented in [7]. Several approximation techniques with respect to the loss term are developed in [8-25]. However, they are somewhat inefficient due to the fact that the procedure of approximation is very complicated and it takes a long time in calculation.

However the conventional power flow analysis has at least two drawbacks due to the existence of slack bus. Here, slack bus supplies the remaining load after supplied by the existing generators and the total system losses. Due to this, in economic load dispatch (ELD) problem the equal incremental cost is not maintained after the power flow calculations. In this paper, a methodology is developed to maintain the equal incremental cost even after performing the load flow solution by removing the extra burden on the slack bus. Similarly, a pseudo load flow formulation is introduced which allows convergence from a much wider angle compared to that of the AC model. It also provides a good starting point to obtain convergence of NR process for AC load flow equations, where the conventional NR load flow diverges.

II. ECONOMIC LOAD DISPATCH PROBLEM

Economic Load Dispatch (ELD) or the optimum scheduling of the generation is the process of allocation of generation among different generating units. Economic scheduling is a cost-effective mode of allocation of generation among the different units in such a way that the overall cost of generation should be minimum. This problem is solved by maintaining the incremental fuel cost (IFC) characteristics for the generators. These characteristics can be obtained as the ratio of a small change in the input to the corresponding small change in the output.

$$\text{Incremental Fuel Cost (IFC)} = \frac{\Delta\, input}{\Delta\, output} = \frac{\Delta F}{\Delta P_G} \qquad (1)$$

Where, ΔF and ΔPG represents small changes in the cost of the fuel input (Rs/hr) and the generation output (MW). The sample IFC characteristics are shown in Fig.1.

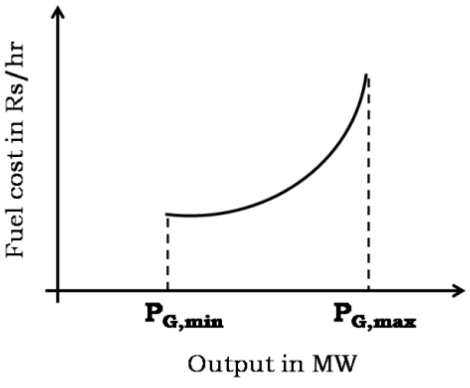

Fig. 1 Incremental fuel cost characteristics

A. Economic Load Dispatch (ELD) problem neglecting losses

The objective function is to minimize the overall cost of production of power generation. Let us consider 'NG' is the total number of units in the system and 'Ci(PGi)' is assumed to be the cost of power generation of unit-i, which is given for each plant. The total generation fuel cost objective function is defined as

$$FC = \sum_{i=1}^{NG} C_i(P_{Gi}) = \sum_{i=1}^{NG} (\alpha i + \beta i P_{Gi} + \gamma i P_{Gi}^2) \qquad (2)$$

Where, αi, βi, γi are the fuel cost coefficients of ith unit. The economic power system operation needs to satisfy the following constraints:

A. Equality constraints

The sum of real power generation of all the various units must always be equal to the total real power demand (PD) on the system.

$$P_D = \sum_{i=1}^{NG} P_{Gi} \qquad (3)$$

B. Inequality constraints

These constraints are considered in an economic power system operation due to the physical and operational limitations of the units and components. Each generating unit should not operate above its rating or below some minimum generation. This minimum value of real power generation is determined from the technical feasibility.

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \qquad (4)$$

B. Mathematical determination of optimal scheduling

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

$$\min\left(FC'\right) = \min\left[FC - \lambda\left[\sum_{i=1}^{NG} P_{Gi} - P_D\right]\right] \qquad (5)$$

The condition for optimality of this augmented function is

$$\frac{\partial FC_1}{\partial P_{G1}} = \frac{\partial FC_2}{\partial P_{G2}} = \frac{\partial FC_3}{\partial P_{G3}} = \cdots = \lambda \qquad (6)$$

After solving Eqn (6) using Eqn (5), we get the necessary conditions for optimal dispatch when losses are neglected is as follows:

$$\frac{\partial FC_i}{\partial P_{Gi}} \begin{cases} = \lambda \;; & for\ P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}; \quad \forall i = 1,2,3,\ldots,NG \\ \le \lambda \;; & for\ P_{Gi} = P_{Gi}^{\max} \quad ; \quad \forall i = 1,2,3,\ldots,NG \\ \ge \lambda \;; & for\ P_{Gi} = P_{Gi}^{\min} \quad ; \quad \forall i = 1,2,3,\ldots,NG \end{cases} \qquad (7)$$

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From Eqn (2) and (7),

$$\beta_i + 2\gamma_i P_{Gi} = \lambda \qquad (8)$$

From this condition,

$$P_{Gi} = \frac{\lambda - \beta_i}{2\gamma_i} \qquad (9)$$

The value of 'P_{Gi}'can be found from Eqn (9) using λ-iterative method using the following steps:

Step 1: Guess the initial value of 'λ0' with the use of cost-curve equations.
Step 2: Calculate PGi using Eqn (9).
Step 3: Check whether equality constraint given in Eqn (3) is satisfying or not.

$$\left(\sum_{i=1}^{NG} P_{Gi} - P_D \le \varepsilon\right) \text{(a tolerance value)}$$

Step 4: If $\sum_{i=1}^{NG} P_{Gi} < P_D$, set a new value for λ, i.e. λ'=λ+Δλ and repeat from step 2 till the tolerance value is satisfied.
Step 5: If $\sum_{i=1}^{NG} P_{Gi} > P_D$, set a new value for λ, i.e. λ'=λ-Δλ and repeat from step 2 till the tolerance value is satisfied.
Step 6: Stop and print the generation schedules.

III. MODIFIED ECONOMIC LOAD DISPATCH PROBLEM FORMULATION

To make a distribution rule in an ELD sense, a new variable P_{loss} is introduced to the ELD formulation as follows:

$$\min\left(\sum_{i=1}^{NG} C_i(P_{Gi})\right)$$

$$\text{subjected to} \sum_{i=1}^{NG} P_{Gi} - P_D - P_{loss} = 0 \qquad (10)$$

where P_{loss} is the the total system losses.

To solve the problem described in Eqn (10), the augmented cost function in terms of Lagrangian multiplier like in Eqn (5) can be written as

$$L = \sum_{i=1}^{NG} C_i(P_{Gi}) + \lambda\left(\sum_{i=1}^{NG} P_{Gi} - P_D - \Delta P_{loss}\right),$$

(λ: Lagrange multiplier) (11)

To get an optimal scheduling of the generators, the conditions that must be satisfied as follows:

$$\frac{\partial L}{\partial \lambda} = \sum_{i=1}^{NG} P_{Gi} - P_D - P_{loss} = 0 \qquad (12)$$

$$\frac{\partial L}{\partial P_{Gi}} = 2\gamma_i P_{Gi} + \beta_i + \lambda = 0 \qquad (13)$$

Upon solving Eqn(13), we get

$$P_{Gi} = \frac{-b_i + \dfrac{P_D}{\left(\sum_{i=1}^{NG}\dfrac{1}{2a_i}\right)} + \sum_{i=1}^{NG}\left[\dfrac{\left(\dfrac{b_i}{2a_i}\right)}{\left(\dfrac{1}{2a_i}\right)}\right]}{2a_i} + \frac{P_{loss}}{2a_i\left(\sum_{i=1}^{NG}\dfrac{1}{2a_i}\right)} \qquad (14)$$

In Eqn (14), the first term represents the scheduled power of the ith generator without considering losses. Hence, this power can be expressed as

$$P_{Gi}^{sch} = \frac{-b_i + \dfrac{P_D}{\left(\sum_{i=1}^{NG}\dfrac{1}{2a_i}\right)} + \sum_{i=1}^{NG}\left[\dfrac{\left(\dfrac{b_i}{2a_i}\right)}{\left(\dfrac{1}{2a_i}\right)}\right]}{2a_i} \qquad (15)$$

From Eqns (14) and (15), PGi can be expressed as follows:

$$P_{Gi}^{new} = P_{Gi}^{sch} + P_{loss} \times pf_i \qquad (16)$$

participation factor is

$$pf_i = \frac{1}{2a_i\left(\sum_{i=1}^{NG}\dfrac{1}{2a_i}\right)}$$

This shows that if some amount of load demand is added to the power systems, it will be distributed to all generators in the ELD sense, which means the maintenance of 'equal incremental cost' that was violated in the conventional power flow analysis. As in the above procedure, the 'equal incremental cost' of each generator bus is maintained after the power flow calculation. In addition, the burden of the slack bus is completely removed by using the above methodology. The modified slack bus power can be calculated using

$$P_{slack} = P_{loss} - \left(\sum_{\substack{i=1\\ \ne slack}}^{NG} P_{Gi} + P_D\right) \qquad (17)$$

IV. FLOW CHART OF THE PROPOSED ELD PROBLEM

The flow chart for the modified ELD problem is shown in Fig.2.

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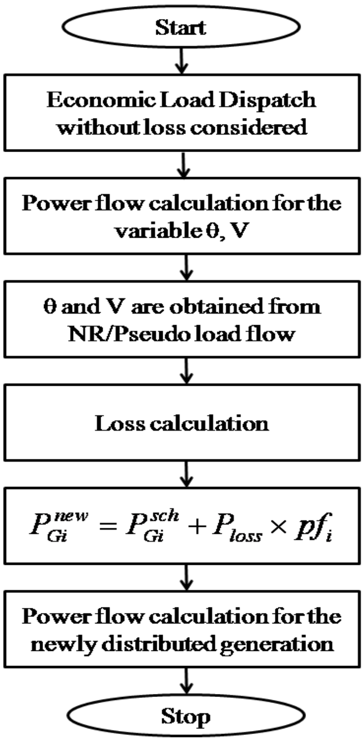

Fig. 2 Flow chart for the modified ELD problem

V. PSEUDO LOAD FLOW FORMULATION

The conventional load flow methods start the process with an initial set of voltages that are closer to the desired solution than the usual flat start. In contrast with this process, quadratic convergence is retained by applying the full NR process and application of the pseudo load flow equations allows convergence of the NR process starts with good solutions. These pseudo load flow equations converges in cases which would the conventional load flow equations diverges.

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

$$P_p = V_p \sum V_q (G_{pq} \cos(\delta_p - \delta_q) + B_{pq} \sin(\delta_p - \delta_q)) \quad (18)$$

$$Q_p = V_p \sum V_q (G_{pq} \sin(\delta_p - \delta_q) - B_{pq} \cos(\delta_p - \delta_q)) \quad (19)$$

where, G_{pq}, B_{pq} are the real and imaginary parts of an admittance matrix (p.u)

Now by applying truncated Taylor series approximation to the conventional load flow equations in (18) and (19),

$$\sin(\delta_p - \delta_q) \cong \delta_p - \delta_q \quad (20)$$

$$\cos(\delta_p - \delta_q) \cong 1 - \left(\frac{(\delta_p - \delta_q)^2}{2}\right) \quad (21)$$

To obtain the set of pseudo load flow equations which have a solution that approximates the AC load flow solution for small values of $|\delta_i - \delta_j|$, from this, the pseudo load flow equations can be expressed as

$$P = V'_p \sum V'_q \left(G_{pq} \left(1 - \left(\frac{(\delta'_p - \delta'_q)^2}{2} \right) \right) + B_{pq} (\delta'_p - \delta'_q) \right) \quad (22)$$

$$Q = V'_p \sum V'_q \left(G_{pq} (\delta'_p - \delta'_q) - B_{pq} \left(1 - \left(\frac{(\delta'_p - \delta'_q{}^2)}{2} \right) \right) \right) \quad (23)$$

The equations are more linear than the original equations, but should have solutions V'_p, δ'_p which are quite close to the new AC load flow solutions.

There are cases where the conventional Newton Raphson method fails to converge which are broadly categorized as:

- Wide angle starting points (voltage angles)
- Heavily loaded networks
- Networks with high levels of shunt reactance

In real time, the system voltage profile is not a flat profile. Hence, in this paper the wide angle starting point constraint with voltage magnitude is 1.0 p.u is considered to verify the effectiveness of the pseudo load flow formulation over the conventional load flow formulation. For example, load flow solution for a sample three bus system starts with the following different voltage angles given in Table.1 to test the convergence of the pseudo load flow formulation.

TABLE I DIFFERENT VOLTAGE ANGLES TO START THE LOAD FLOW PROBLEM

δ_1 (deg)	δ_2 (deg)	δ_3 (deg)
0.0	0.0	0.0
0.0	-0.5	-1.0
0.0	-1.0	-2.0
0.0	-1.5	-3.0

VI. RESULTS AND ANALYSIS

In this section, the developed methodology is tested on IEEE-9 bus test system. For this system, generator at bus-1 is the slack bus. The total analysis part is performed in the following two scenarios.

- In first scenario, the burden on the slack bus is removed by following the methodology given in section 3 and the modified ELD problem is solved using the procedure given in section 5 using the conventional NR load flow solution.
- In second scenario, to show the effectiveness of the pseudo load flow problem formulation and to make the problem more realistic, the entire procedure given in

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scenario-1 is performed with wide angles constraint. For this, in this paper, the voltage angle at the highest load consisted bus is varied from -20 deg to +20 deg in steps of 40 deg.

A. Test system-1

IEEE-9 bus test system with thirteen transmission lines and two generators located at buses 2, 6, one tap changing transformers located between buses 2-7. For this system, the total active load is 259 MW.

A. Scenario-1

Results of the conventional ELD problem are tabulated in Table.2.

TABLE III RESULTS OF ELD WITHOUT LOSSES FOR IEEE-9 BUS TEST SYSTEM

Control parameter		Optimal schedules (P_G^{sch})
Power Generations (MW)	P_{G1}	91.3
	P_{G2}	76.4762
	P_{G3}	91.3
Total generation, MW		259.0762
IFC value (Rs/MWhr)		14.6062

By using these generation values, conventional NR load flow problem is solved and load flow results are tabulated in Tables.3 and 4. From Table.3, it is identified that, the slack generation is changed from 91.3 MW to 92.786 MW; this is due to supplying the total power losses which violates the incremental cost characteristics of generators for ELD problem.

TABLE IIIII LOAD FLOW RESULTS WITH NEW SCHEDULES FOR IEEE-9 BUS SYSTEM

Control parameter		Generator schedules (P_G^{sch}) from	
		ELD	NR load flow
Power Generations (MW)	P_{G1}	91.3	92.786
	P_{G2}	76.4762	76.4762
	P_{G3}	91.3	91.3
Total generation, (MW)		259.0762	260.5622
IFC value(Rs/MWhr)		14.6062	-
Total power losses(MW)		0.0000	1.486

TABLE IVV NR LOAD FLOW RESULTS FOR IEEE-9 BUS SYSTEM

Bus No	Voltage Magnitude (p.u)	Voltage Angle (rad)
1	1.06	0
2	1.04	0.9832
3	1.03356	-0.5982
4	1.0307	-0.4752
5	1.0281	3.7777
6	1.025	5.3471
7	1.0958	0.8315
8	1.0738	0.3449
9	1.048	-0.3228

Using the proposed methodology, the participation factors are calculated for each of the generators using Eqn (10) and these values are tabulated in Table.5. Using these participation factors, new generations are calculated using the Eqn (17) and these values are tabulated in Table.5. Using these new generations, NR load flow problem is solved and the obtained generations are also tabulated in Table.5. From this table, it is identified that, the property of the participation factors i.e. sum of participation factors is equal to one. It is also identified that, the new generations obtained and the generation obtained from NR load flow are very similar and the total power losses obtained are very closer to the original power losses. From these results, it is summarized that, the proposed methodology reduces the burden on the slack bus by distributing the losses to the remaining generators based on their participation factors.

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TABLE V PARTICIPATION FACTORS AND MODIFIED GENERATIONS FOR IEEE-9 BUS SYSTEM

	Control parameters	Participation Factor (Pf)	Generator schedules		
			ELD (P_G^{sch})	Modified (P_G^{new})	NR load flow
Power Generations (MW)	P_{G1}	0.3412	91.3	91.8098	91.8122
	P_{G2}	0.3426	76.4762	76.9	76.9236
	P_{G3}	0.3432	91.3	91.8098	91.8122
Total generation(MW)		1.0000	259.0762	260.5196	260.548
Total power losses(MW)			0.0000	1.4434	1.4718

B. Scenario-2

To show the effectiveness and to make the problem more realistic the process performed in scenario-1 is repeated with pseudo load flow equations instead of NR load flow equations. For this system, the highest load consisted bus is 2 , hence, the voltage profiles tabulated in Table.6 are considered. Here, profile-1 is a flat voltage profile presented in scenario-1.

TABLE VI VOLTAGE PROFILES FOR PSEUDO LOAD FLOW PROBLEM FOR IEEE-9 BUS SYSTEM

Bus No	**Voltage magnitude (p.u)**	**Voltage angle (deg)**		
		Profile-1	**Profile-2**	**Profile-3**
1	1.06	0	0	0
2	1.04	0	0	0
3	1.03356	0	-10	10
4	1.0307	0	0	0
5	1.0281	0	0	0
6	1.025	0	0	0
7	1.0958	0	0	0
8	1.0738	0	0	0
9	1.048	0	0	0

The load flow results obtained using conventional NR load flow equations are tabulated in Table.7. The variation of voltage magnitudes and voltage angles for the three profiles are shown in Figs. 3 and 4. From this analysis, it is identified that, voltage magnitudes and voltage angles have considerable variations as the voltage angle profile is varied.

TABLE VII NR LOAD FLOW RESULTS FOR THE DIFFERENT VOLTAGE ANGLE PROFILES FOR IEEE- 9 BUS SYSTEM

Bus No	**Voltage Magnitude(p.u)**			**Voltage Angle(rad)**		
	Profile-1	**Profile-2**	**Profile-3**	**Profile-1**	**Profile-2**	**Profile-3**
1	1.06	1.06	1.06	0	0	0
2	1.04	1.0125	1.0025	0.9832	1.0273	2.9413
3	1.03356	1.0246	1.0169	-0.5982	-0.4692	-0.3211
4	1.0307	0.9951	0.9412	-0.4752	-0.2658	-0.0792
5	1.0281	1.0161	0.9989	3.7777	6.6548	10.1924
6	1.025	0.9976	0.9762	5.3471	7.6532	9.998
7	1.0958	1.0724	1.0543	0.8315	1.2078	1.4691
8	1.0738	1.0564	1.0226	0.3449	0.7619	0.9234
9	1.048	1.0303	0.9876	-0.3228	-0.1249	-0.0245

TABLE VIII PSEUDO LOAD FLOW RESULTS FOR THE DIFFERENT VOLTAGE ANGLE PROFILES FOR IEEE-9 BUS SYSTEM

Bus No	**Voltage Magnitude (p.u)**						**Voltage Angle (rad)**					
	Profile-1		**Profile-2**		**Profile-3**		**Profile-1**		**Profile-2**		**Profile-3**	
	NR	**Pseudo**	**NR**	**Pseudo**	**NR**	**Pseudo**	**NR**	**Pseudo**	**NR**	**Pseudo**	**NR**	**Pseudo**
1	1.06	1.06	1.06	1.06	1.06	1.06	0	0	0	0	0	0

2	1.04	1.04	1.0125	1.0163	1.0025	1.0625	0.9832	1.025	1.0273	0.5815	2.9413	2.372
3	1.03356	1.03352	1.0246	1.035	1.0169	1.078	-0.5982	-0.5129	-0.4692	-0.9342	-0.3211	-0.8841
4	1.0307	1.031	0.9951	1.0034	0.9412	1.003	-0.4752	-0.4045	-0.2658	-0.7603	-0.0792	-0.6215
5	1.0281	1.0282	1.0161	1.025	0.9989	1.062	3.7777	3.8840	6.6548	6.1098	10.1924	8.9342
6	1.025	1.023	0.9976	1.003	0.9716	1.0327	5.3471	5.5232	7.6532	7.2074	9.998	9.3217
7	1.0958	1.0956	1.0724	1.083	1.0543	1.1154	0.8315	0.9004	1.2078	0.8939	1.4691	0.9268
8	1.0738	1.0736	1.0564	1.092	1.0226	1.09	0.3449	0.4056	0.7619	0.3161	0.9234	0.3811
9	1.048	1.044	1.0303	1.053	0.9876	1.042	-0.3228	-0.2821	-0.1249	-0.5707	-0.0245	-0.5668

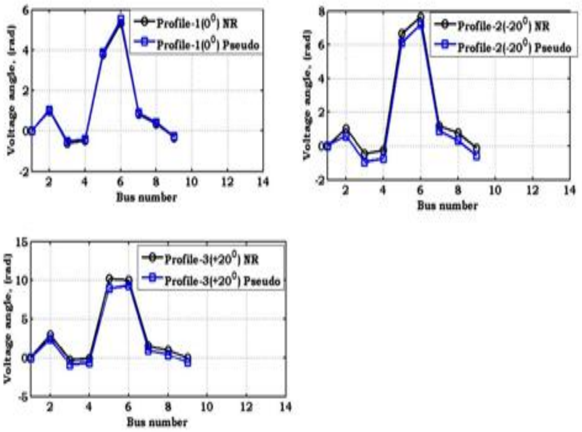

Fig. 3 Variation of voltage angles with pseudo load flow for different profiles for IEEE-9system

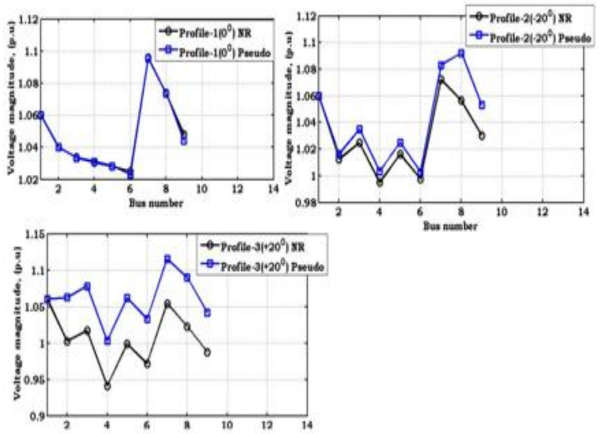

Fig. 4 Variation of voltage magnitude with pseudo load flow for different profiles for IEEE-9system

The total power losses in all these cases are tabulated in Table.9. From this table, it is identified that, the total power losses (TPL) are decreased with the developed Pseudo load flow formulation when compared to the existing NR load flow formulation. It is also identified that, the total number of iterations taken for convergence are reduced with the developed load flow method.

Finally, the ELD problem for these three profiles is solved by removing the burden on the slack bus. The optimal schedules for all the generators in for these profiles are tabulated in Table.10. From this table, it is identified that, the developed Pseudo load flow solution yields better results when compared to the existing NR load flow solutions in terms of the total power losses and in terms of the total number of iterations taken for convergence.

From the above analysis, it is summarized that, the developed Pseudo load flow formulation decreases the total number of iterations for convergence and as well as, it is possible to reduce the slack burden to maintain the equal incremental fuel cost characteristics to solve ELD problem effectively.

TABLE IX TOTAL POWER LOSSES FOR THE DIFFERENT VOLTAGE ANGLE PROFILES FOR IEEE-9 BUS SYSTEM

	Profile-1		**Profile-2**		**Profile-3**	
	NR	**Pseudo**	**NR**	**Pseudo**	**NR**	**Pseudo**
TPL Value (MW)	2.5864	2.4319	4.7619	2.5296	6.3231	3.1332
Number of Iterations	5	5	7	6	8	6

TABLE X MODIFIED GENERATIONS FOR IEEE-9 BUS SYSTEM

Control Parameters		**Generator schedules**									
		ELD **($P_G{}^{sch}$)**	**Profile-1**			**Profile-2**			**Profile-3**		
			Modified ($P_G{}^{new}$)	**Load flow**		**Modified ($P_G{}^{new}$)**	**Load flow**		**Modified ($P_G{}^{new}$)**	**Load flow**	
				NR	**Pseudo**		**NR**	**Pseudo**		**NR**	**Pseudo**
Power	P_{G1}	91.3	91.8098	91.8122	91.6095	91.0954	91.0969	91.0812	92.4367	92.4364	92.4125

generations	P_{G2}	76.4762	76.9	76.9236	76.9124	77.6541	75.9167	76.0132	76.0542	76.01219	76.1249
	P_{G3}	91.3	91.8098	91.8122	91.6099	91.9128	93.9929	93.6184	95.1222	95.2453	92.399
Total generation (MW)		259.0762	260.5196	260.548	260.1318	260.6623	261.0934	260.7128	263.6131	263.6946	260.9364
Total power losses (MW)		0.0000	1.4434	1.4728	1.0556	1.5861	2.0172	1.6366	4.5369	4.6184	1.8602

VII. CONCLUSION

In this paper, two important methodologies have been developed to solve the most realistic power system optimization problem namely economic load dispatch problem. At first, a methodology to remove the extra burden on slack bus has been proposed removed by distributing the total system power losses to the remaining generators based on their participation factors. From the analytical results, it has been summarized that, the developed methodology maintains equal incremental cost characteristics for the generators which has the equal generation fuel cost characteristics. Secondly, to improve the effectiveness and to solve the more realistic power system load flow problem, Pseudo load flow equations have been formulated using Taylor's approximations. Using these equations, the effectiveness of the load flow solution under wide voltage angle variations has been enhanced. The developed Pseudo load flow equations converges the power flow problem in less number of iterations when compared to the existing NR load flow equations. Further, the ELD problem has been solved using the developed Pseudo load flow equations. From this, it has been summarized that, the developed Pseudo load flow equations takes less time to remove the extra burden on the slack bus to main the equal incremental fuel cost characteristics for the generators.

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