Nur Azzammudin Rahmat[1,*], **Ismail Musirin**[2], **Ahmad Farid Abidin**[1]

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Solving Multi-Pollutant Emission Dispatch Problem Using Computational Intelligence Technique

Economic dispatch is a crucial process conducted by the utilities to correctly determine the satisfying amount of power to be generated and distributed to the consumers. During the process, the utilities also consider pollutant emission as the consequences of fossil-fuel consumption. Fossil-fuel includes petroleum, coal, and natural gas; each has its unique chemical composition of pollutants i.e. sulphur oxides (SO_X), nitrogen oxides (NO_X) and carbon oxides (CO_X). This paper presents multi-pollutant emission dispatch problem using computational intelligence technique. In this study, a novel emission dispatch technique is formulated to determine the amount of the pollutant level. It utilizes a pre-developed optimization technique termed as differential evolution immunized ant colony optimization (DEIANT) for the emission dispatch problem. The optimization results indicated high level of CO_X level, regardless of any type of fossil fuel consumed.

Keywords: emission dispatch, computational intelligence, fossil fuel.

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1. Introduction

The abundances and low-priced fossil-fuel such as coal, petroleum, and natural gas encourages the high demand on the establishment of fossil-fueled power plants [1, 2]. As the consequence, thermal power plants continue to serve as the main choice for generating energy. However, the increasing number of fossil-fueled power plant contributes to the increasing level of pollutant released to the environment [3, 4]. In electrical power system, thermal power plants fired by fossil-fuel were among the major contributors to the decreasing of air quality by expelling out pollutant such as sulphur oxides (SO_X), nitrogen oxides (NO_X) and carbon oxides (CO_X) [5-8]. These pollutants are the by-product of industrial processes, high temperature combustion, electricity discharge and incomplete fuel combustion [9]. Clean Air Amendments of 1990 have forced the electrical utilities to reduce the emission from thermal power plant [10-12]. Numerous techniques which vary between anti-pollutants instruments and environmental policies have been introduced to manage pollution level as discussed in [13, 14]. The techniques include the installation of pollutant cleaning equipment such as carbon capture and storage (CCS) [15], low emission fuels, "clean coal" technology [16-18], and emission dispatch [5, 19].

This research presents solving multi-pollutant emission dispatch problem using computational intelligence technique. A research on emission dispatch was conducted based on economic load dispatch problem. In this study, economic load dispatch problem

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[*] Corresponding author: Centre for Power Engineering Studies, Faculty of Electrical Engineering, Universiti Teknologi Mara, Malaysia

[1] Centre for Power Engineering Studies, Faculty of Electrical Engineering, Universiti Teknologi MARA, Malaysia

[2] Community of Research (CoRe), Advanced Computing and Communication (ACC), Universiti Teknologi Mara, MALAYSIA

were taken as the groundwork of the emission dispatch problem formulation. Emission dispatch formula will be used to calculate the pollutant level emitted by each generator in the system and calculate the operating cost. The emission level is the amount of pollutant expelled by the generator, measured in kilogram per-hour unit. Types of pollutants vary according to the type of fuel fed to the generator. Emission dispatch was conducted on IEEE Bus Systems including the 57-Bus and 118-Bus System. DEIANT technique is used as the optimization engine for solving the proposed emission dispatch problem.

2. Notation

The notation used throughout the paper is stated below.

ρ_{sel}	The selected pheromone
$\rho(m,n)$	Current pheromone trace
$\rho(m_n,n_n)$	New pheromone trace
$\rho(m_g,n_g)$	Global pheromone trace
$\rho(m,n)$	Current pheromone trace
d	Distance of ant tour
d_{max}	Maximum distance
E_{CO}	Emission level for CO_x
E_{NO}	Emission level for NO_x
E_{SO}	Emission level for SO_x
E_{tot}	The emission level
f_i	Travelled distance
f_{max}	Maximum distance
$J_{k(r)}$	Set of unvisited nodes in order to make feasible solution
r	Current node
s	Next node
u	Unvisited node
X_{i+m}	Pheromone mutation function
X_{jmax}	Largest node number
X_{jmin}	Smallest node number
x_{max}	Maximum value of control variable
α_{CO}, β_{CO}, γ_{CO}, δ_{CO}	Emission coefficient for CO_x
α_{NO}, β_{NO}, γ_{NO}, δ_{NO}	Emission coefficient for NO_x
α_{SO}, β_{SO}, γ_{SO}, δ_{SO}	Emission coefficient for SO_x
η	$1/d$ is the inverse of the distance $d(r,s)$
P	Pheromone trail
ρ	The original pheromone
ρ_e	Pheromone evaporation rate
ρ_e	Pheromone evaporation rate

3. The Proposed Multi-pollutant Emission Dispatch Formulation

This research includes three common emission produced by thermal-plants namely; SO_x, CO_x, and NO_x. They are considered as the by-product of a specific fuel-type. Each type of emission has a specific quadratic equation. Equation (1) to (3) presents the emission level for SO_x CO_x and NO_x respectively:

$$E_{SO}=\sum_{i=1}^{n}(\alpha_{SO}P_i^3+\beta_{SO}P_i^2+\gamma_{SO}P_i+\delta_{SO}) \tag{1}$$

$$E_{CO}=\sum_{i=1}^{n}(\alpha_{CO}P_i^3+\beta_{CO}P_i^2+\gamma_{CO}P_i+\delta_{CO}) \tag{2}$$

$$E_{NO}=\sum_{i=1}^{n}(\alpha_{NO}P_i^3+\beta_{NO}P_i^2+\gamma_{NO}P_i+\delta_{NO}) \tag{3}$$

To calculate the total emission level, equation (1) to (3) is combined into equation (4) below:

$$E_{tot}=\sum_{i=1}^{n}\begin{bmatrix}(\alpha_{SO}P_i^3+\beta_{SO}P_i^2+\gamma_{SO}P_i+\delta_{SO})+\\(\alpha_{CO}P_i^3+\beta_{CO}P_i^2+\gamma_{CO}P_i+\delta_{CO})+\\(\alpha_{NO}P_i^3+\beta_{NO}P_i^2+\gamma_{NO}P_i+\delta_{NO})\end{bmatrix} \tag{4}$$

The emission dispatch is measured in tons per hour (tons/hour). Emission dispatch will be run together with economic load dispatch (ELD) problem.

4. Differential Evolution Immunized Ant Colony Optimization Formulation

Differential Evolution Immunized Ant Colony Optimization (DEIANT) algorithm is inspired from conventional Ant Colony Optimization (ACO) and Differential Evolution (DE) algorithms [20]. Cloning process inspired from Artificial Immune System (AIS) is also integrated to further enhance the algorithm computational capabilities the process of DEIANT is depicted in Figure 1.

4.1. Initialization

DEIANT algorithm heuristically initializes the number of ants, number of nodes, and pheromone decay factor. Parameters such as *scout-ant* cloning factor, pheromone mutation factor, and crossover constant are also heuristically initialized. The first node is also heuristically determined, before being updated during the next iterations.

4.2. Transition Rule

The next node is selected based on a transition rule. During the travel from one node to another, each ant must not visit any visited node.

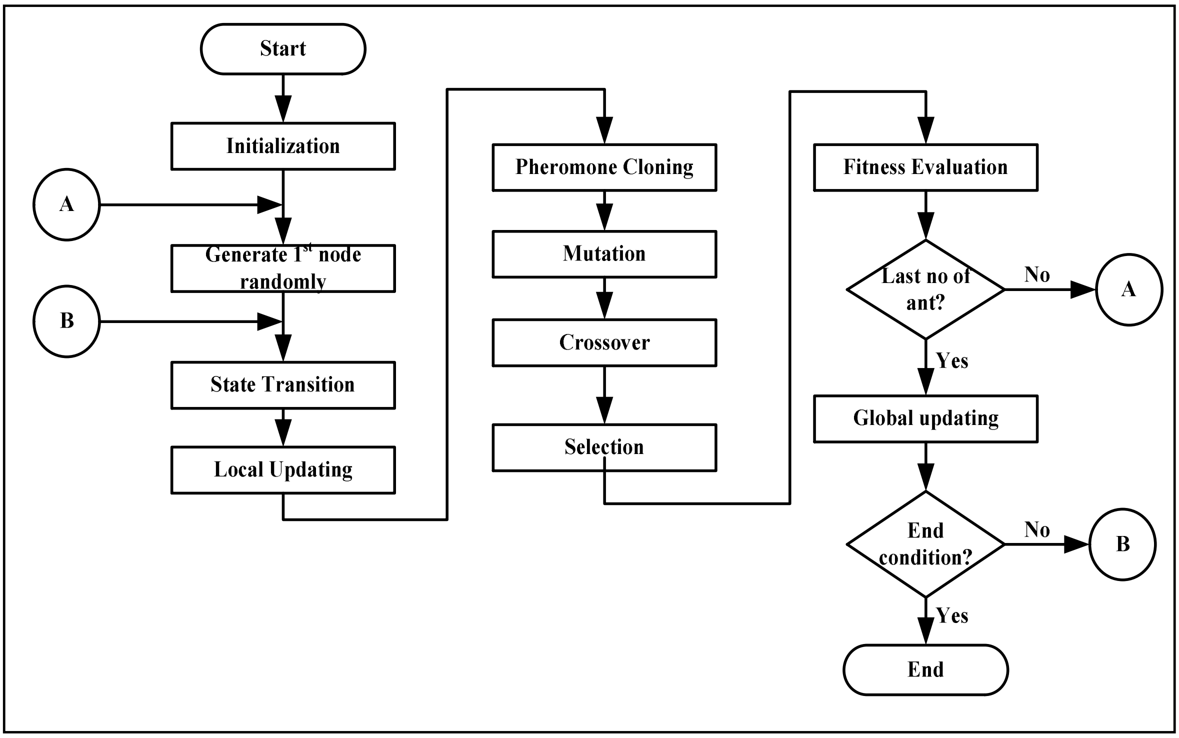

Figure 1: DEIANT Flowchart

4.3. Local Updating Rule

In this research, the shortest path will have the highest pheromone level. Each ant will update the pheromone level according to the evaporation factor, ρ. The evaporation rate will prevent any unwanted accumulation of pheromone layer.

4.4. Pheromone Cloning

Based on Artificial Immune System (AIS), the pheromone matrix is duplicated to create an identical replication of the original matrix. The duplicated pheromone matrix will go through mutation process.

4.5 Pheromone Mutation

In this research, mutation is used to enhance pheromone layer diversity by modifying the elements of the pheromone matrix. The mutated pheromone matrix is termed as the parents.

4.6. Crossover

The original and the mutated pheromone matrices are combined into one matrix. Next, the content of matrix is sorted in descending order (from larger number to smaller number).

4.7. Selection

In this research, selection process starts by normalizing ρ_X and ρ_{mat}. Next, based on the fitness, the normalized matrix is sorted in descending order. If ρ_{sel} is better than ρ, therefore, ρ_{sel} will be selected and vice versa.

4.8. Control Variable

In this research, the control variable will be the maximum and minimum power of generation level, P_{max} and P_{min}, respectively.

4.9. Global Updating Rule

The fittest ant from the colony will be selected during the global updating rule. The fittest ant will bring the best solution. The best ant will update the pheromone layer. The first node from the best solution will be assigned as the first node of the next iteration.

4.10. Termination

The algorithm will terminate its processes either when it reaches the maximum number of iteration, or when the best solution has been yielded.

5. Result and Discussion

In this research, the pollutant-based emission dispatch is implemented on IEEE 57-Bus System. The objective is to minimize the emission level of NO_x, SO_x, and CO_x. The results of this study are tabulated in Table 1 and Table 2. Table 1 tabulates the optimization of emission dispatch of IEEE 57-Bus system. The generators are simultaneously fed with three types of emission namely; coal, petroleum and natural gas. Based on Table 1, generators fuelled with natural gas emit the lowest CO_x level (2.98 tons/hour) compared to petroleum (3.31 tons/hour). Generators fed with coal produced the highest CO_x level (3.34 tons/hour).

Table 2 to Table 4 tabulates the comparative studies of DEIANT, ACO, PSO and EP conducted on the pollutant-based emission dispatch with the generators are fed with coal, petroleum, and natural gas respectively. The studies were conducted on IEEE 57-Bus system. The comparative studies indicate the superiority of DEIANT over ACO, PSO and EP. DEIANT computed lower emission level, power loss, and computation time. For example, by referring to Table 3, DEIANT computed lower CO_x level (3.2817 tons/hour) as compared to ACO, PSO and EP. The computation time for DEIANT to compute the emission level is significantly faster than ACO, PSO and EP.

Table 1: Optimization of Emission Dispatch of IEEE 57-Bus System Based on Fuel Types by Using DEIANT Technique

Generator		G_1	G_2	G_3	G_4	G_5	G_6	G_7	E_{n_Tot}	E_{Tot}	C_{Tot}
Coal (tons/ hour)	CO_x	0.50	0.34	0.16	0.27	0.36	0.35	1.31	3.29	3.34	41101.04
	NO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		
	SO_x	0.01	0.00	0.00	0.00	0.00	0.00	0.02	0.04		
	E_{Tot}	0.51	0.34	0.17	0.27	0.37	0.36	1.33	3.34		
Petro-leum (tons/ hour)	CO_x	0.50	0.33	0.16	0.27	0.36	0.35	1.30	3.28	3.31	41288.62
	NO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01		
	SO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02		
	E_{Tot}	0.51	0.34	0.17	0.27	0.36	0.35	1.32	3.31		
Nat. Gas (tons /hour)	CO_x	0.46	0.30	0.15	0.24	0.33	0.32	1.18	2.98	2.98	41642.94
	NO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	SO_x	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
	E_{Tot}	0.46	0.30	0.15	0.24	0.33	0.32	1.19	2.98		
P_{GEN} (MW)		140.00	93.13	45.75	74.17	462.72	97.63	364.02	1277.42		

Table 2: Comparative Studies of Emission Dispatch on Coal Consumption in IEEE 57-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	3.2889	3.2914	3.3124	3.2920
E_{SOx} (Tons/hour)	0.0431	0.0453	0.04593	0.0455
E_{NOx} (Tons/hour)	0.011	0.011	0.0012	0.0011
Time (s)	7.2702	19.6882	25.3873	22.6616

Table 3: Comparative Studies of Emission Dispatch on Petroleum Consumption in IEEE 57-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	3.2817	3.3422	3.3320	3.3423
E_{SOx} (Tons/hour)	0.0251	0.0287	0.0288	0.0288
E_{NOx} (Tons/hour)	0.011	0.011	0.0011	0.0011
Time (s)	7.3443	20.3415	23.4542	25.4394

Table 4: Comparative Studies of Emission Dispatch on Natural Gas Consumption in IEEE 57-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	2.9781	2.9834	3.1189	2.9931
E_{SOx} (Tons/hour)	0.0014	0.0014	0.0015	0.0015
E_{NOx} (Tons/hour)	0.010	0.010	0.0011	0.0010
Time (s)	8.5332	21.4388	24.6657	22.7655

Next, the research is conducted on a larger test system, which is the IEEE 118-Bus system. Similarly, the objective is to minimize the emission level of NO_x, SO_x, and CO_x. The generators are simultaneously fed with three types of emission namely; coal, petroleum and natural gas. The results are tabulated in Table 5, Table 6, Table 7, and Table 8.

Table 5 tabulates the optimization of emission dispatch of IEEE 118-Bus system. The results in Table 5 reflect similar pattern of emission dispatch as in Table 1; the results indicates that CO_x is the highest pollutant emitted due to fuel combustion. For example, coal produces 10.3728 tons/hour of CO_x, petroleum produces 10.3196 tons/hour of CO_x, and natural gas produces 9.3673 tons/hour of CO_x. The results also indicate that natural gas is slightly cleaner than coal and petroleum.

Table 5: Optimization of Emission Dispatch of IEEE 118-Bus System Based on Fuel Types by Using DEIANT Technique

Fuel		E_{n_Tot} (tons/hour)	E_{Tot} (tons/hour)	C_{Tot} (\$/hour)
Coal (tons/hour)	COx	10.3728	10.5201	163038.33
	NOx	0.0210		
	SOx	0.1262		
Petro-leum (tons/hour)	COx	10.3196	10.4186	163782.42
	NOx	0.0281		
	SOx	0.0708		
Nat. Gas (tons/hour)	COx	9.3673	9.3767	165187.92
	NOx	0.0094		
	SOx	0.0000		

Next, comparative studies are also conducted on the IEEE 118-Bus system. The comparative studies involve DEIANT, ACO, PSO and EP as the optimization engines. The comparative studies are tabulated in Table 6, Table 7, and Table 8. The comparative studies indicate the superiority of DEIANT over ACO, PSO and EP. DEIANT computed lower emission level, power loss, and computation time. For example, by referring to Table 6, DEIANT computed lower CO_x level (10.3728 tons/hour) as compared to ACO, PSO and EP. The computation time for DEIANT to compute the emission level is also significantly faster than ACO, PSO and EP.

Table 6: Comparative Studies of Emission Dispatch on Coal Consumption in IEEE 118-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	10.3728	10.68	10.72	10.79
E_{SOx} (Tons/hour)	0.1262	0.1310	0.1317	0.1297
E_{NOx} (Tons/hour)	0.0210	0.0215	0.0226	0.0216
Time (s)	10.2342	22.4509	22.8433	25.0028

Table 7: Comparative Studies of Emission Dispatch on Petroleum Consumption in IEEE 118-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	10.3196	10.6341	10.7301	10.7267
E_{SOx} (Tons/hour)	0.0708	0.0724	0.0751	0.0756
E_{NOx} (Tons/hour)	0.0281	0.0300	0.0301	0.02991
Time (s)	11.5632	21.6822	23.4441	22.8139

Table 8: Comparative Studies of Emission Dispatch on Natural Gas Consumption in IEEE 118-Bus System

Technique	DEIANT	ACO	PSO	EP
E_{COx} (Tons/hour)	9.3673	9.6532	9.7343	9.7419
E_{SOx} (Tons/hour)	0.0000	0.0000	0.0000	0.0000
E_{NOx} (Tons/hour)	0.0094	0.0098	0.0119	0.0112
Time (s)	10.2810	22.0931	23.7523	23.5633

6. Conclusion

This research proposed solving multi-pollutant emission dispatch problem using computational intelligence technique. Three types of fossil fuels are focused in this study including coal, petroleum, and natural gas. The study focused on three of the major pollutant composition by fossil fuel consumptions; CO_x, NO_x, and SO_x composition. By using DEIANT to optimize the proposed emission dispatch technique, it is revealed that CO_x is the major composition of the emission.

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