Under the patronage of **H.E. Dr. Abdullah Belhaif Al Nuaimi** - Minister of Infrastructure Development

OMAINTEC CONFERENCE EXHIBITION 2019

17th Edition

—

International Operations & Maintenance Conference in the Arab Countries

19, 20, 21 NOV 2019
Le Meridien Dubai Hotel
& Conference Centre
United Arab Emirates

Under the Theme:
Enhancing Maintenance Through Big Data Management

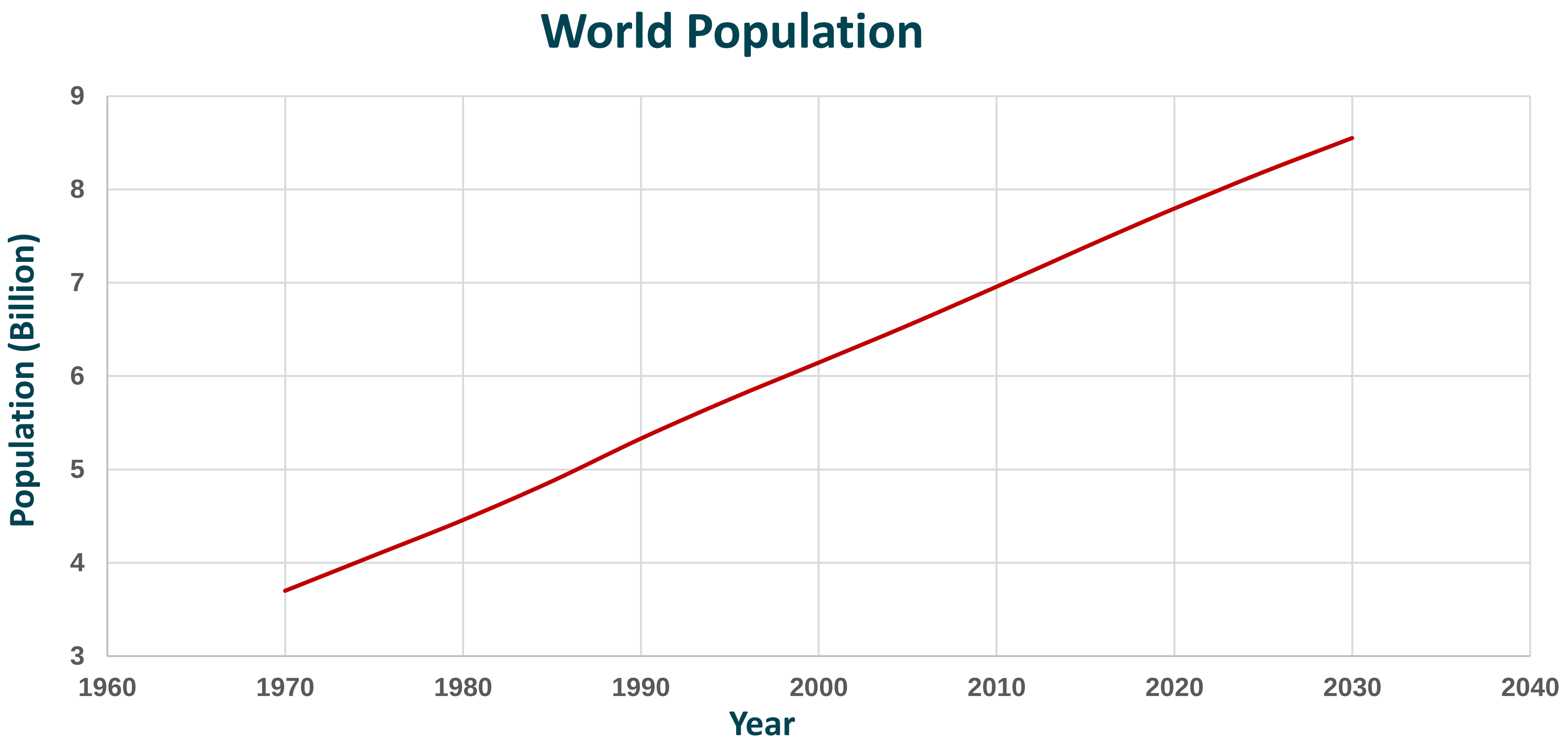
Environmental Economic Dispatch of Thermal Power Plants in Saudi Arabia: A Case Study

INTRODUCTION

- The world demand for electricity is increasing in exponential manner with population

- There are more than 7.8 billion people now on the planet (Fig.1)

INTRODUCTION



INTRODUCTION

Environment Issues

- CO_2 and NO_x effects
- Health Issues
- Environmental Issues

Vision 2030

- Decrease consumption of oil
- Renewable Energy

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

The problem is to minimize the total fuel cost

$$\sum_{i=1}^{n} C_i = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i$$

Where

C_i	Fuel cost of power plant i
a_i, b_i *and* c_i	Cost coefficients of power plant i
n	Number of controllable power plant.
P_i	Power output of power plant i

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

Equality constraints

$$P_T = P_D + P_{loss}$$

Where

P_T	Total generated power
P_{loss}	Transmission Loss
P_D	Total Load Demand

Inequality constraints

$$P_{i,min} \leq P_i \leq P_{i,max}$$

▸▸ ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

Transmission Loss can be found by

$$P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j$$

Where

P_i	Power output of power plant i
P_j	Power output of power plant j
B_{ij}	Losses Matrix

The input is the system load demand and the output is economic power generation and environmental emissions of various power plants

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

For CO_2 Constraints

$$\sum_{i=1}^{n} E1_i = \sum_{i=1}^{n} d1_i P_i^2 + e1_i P_i + f1_i$$

Where

$E1_i$	Total emission of CO_2 for power plant i
$d1_i, e1_i$ *and* $f1_i$	CO_2 emission coefficients of power plant i

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

For NO_x constraints

$$\sum_{i=1}^{n} E2_i = \sum_{i=1}^{n} d2_i P_i^2 + e2_i P_i + f2_i$$

Where

$E2_i$	Total emission of NO_x for power plant i
$d2_i, e2_i$ *and* $f2_i$	NO_x emission coefficients of power plant i

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

Total augmented cost can be obtained by

$$\sum_{i=1}^{n} Ct_i = \sum_{i=1}^{n} (w_1 C_i + w_2 E1_i + w_3 E2_i)$$

ENVIRONMENTAL ECONOMIC DISPATCH: PROBLEM FORMULATION

Different emission conditions may occur by varying w_1, w_2 and w_3 as

w_1	w_2	w_3	Dispatch Type
1	0	0	Economic Dispatch (ED)
0	1	0	Environmental Dispatch with CO_2 Emission Constraints (ED - CO_2 emission)
0	0	1	Environmental Dispatch with NO_x Emission Constraints (ED - NO_x emission)
0.5	0.25	0.25	Combined Environmental Economic Dispatch (EED)

ENVIRONMENTAL ECONOMIC DISPATCH ALGORITHM

For The sequence of major computations of the algorithm is as follows:

i. Get the total load demand data

ii. Assume the load demand is distributed equally among all the thermal plants and there are no losses and set the Lagrange multiplier $\frac{dC}{dP} = \lambda$

iii. Calculate the Pi of each power plant by using the coordination equation $\frac{dC}{dP_i} + \lambda \frac{\partial P_{loss}}{\partial P_i} = \lambda$

ENVIRONMENTAL ECONOMIC DISPATCH ALGORITHM

iv. Check the inequality by $P_{i.min} \leq P_i \leq P_{i,max}$

v. Calculate the power loss by

vi. Check if $\left| \sum P_i - (P_D + P_{loss}) \right| < \varepsilon$

Where ε is the assigned tolerance. If Yes, proceed to print the results; If No, modify the value of λ and go back to step – iii.

▸▸ SYSTEM DATA

System Data: Power plants and the Loss Coefficients

Power Plant no.	a	b	c	P min (MW)	P max (MW)
1	0.001540	8.2716	225.360	1384	5538
2	0.000950	9.2233	253.050	381	1527
3	0.012490	11.8000	153.330	103	412
4	0.000885	8.8167	197.050	171	684
5	0.011040	7.7918	201.280	420	1680
6	0.050400	7.9664	217.110	206	827
7	0.016280	7.8225	213.440	123	494

SYSTEM DATA

CO_2 Emissions Coefficients

Power Plant no.	d_1	e_1	f_1
1	0.2651	-61.02	5080.148
2	0.1401	-29.952	3824.77
3	0.1059	-9.5528	1342.851
4	0.1064	-12.736	1819.625
5	0.1059	-9.5528	1342.851
6	0.4031	-121.98	11381.07
7	0.1064	-12.736	1819.625

SYSTEM DATA

NO_x Emissions Coefficients

Power Plant	d_2	e_2	f_2
1	0.006323	-0.38128	80.90
2	0.006480	-0.79027	28.82
3	0.003174	-1.36061	324.20
4	0.006732	-2.39928	610.30
5	0.003174	-1.36061	324.20
6	0.006181	-0.39077	50.81
7	0.006732	-2.39928	610.30

▸▸ SYSTEM DATA

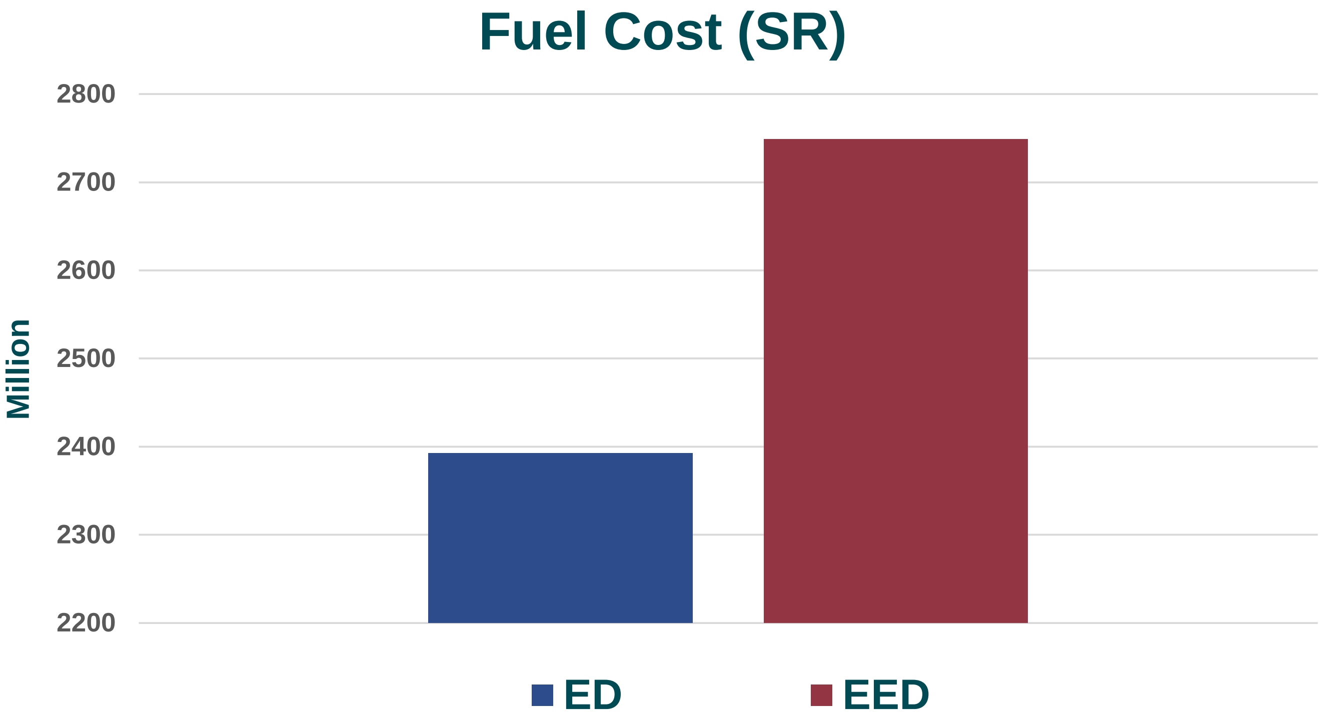
The Losses matrix B

$$B = 10^{-5} * \begin{bmatrix} 2.0 & 1.0 & 0.15 & 0.005 & 0.001 & -0.03 & 0.02 \\ 1.0 & 3.0 & -0.02 & 0.01 & 0.012 & 0.01 & -0.1 \\ 0.15 & -0.02 & 0.1 & -0.1 & 0.1 & 0.001 & 0.04 \\ 0.005 & 0.01 & -0.1 & 15.0 & 0.06 & 5.0 & 0.15 \\ 0.001 & 0.012 & 0.1 & 0.06 & 0.4 & 2.0 & 0.01 \\ -0.03 & 0.01 & 0.001 & 5.0 & 2.0 & 0.5 & 0.4 \\ 0.02 & -0.1 & 0.04 & 0.15 & 0.01 & 0.4 & 0.1 \end{bmatrix}$$

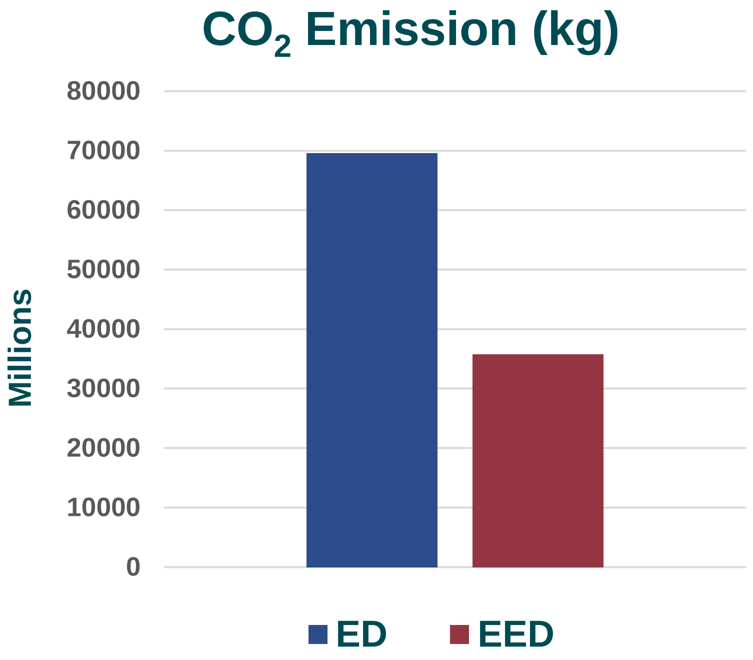
ANNUAL COST AND EMISSION RESULTS

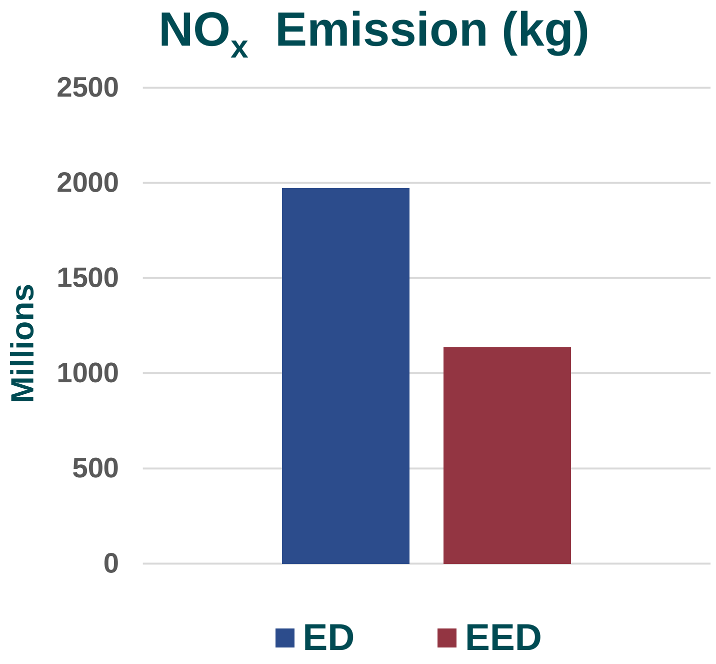
	Economic Dispatch				Environmental Economic Dispatch				% Difference in Annual Estimates
	Typical Day			*Total Annual Estimate in millions*	*Typical Day*			*Total Annual Estimate in millions*	*[(A-B)/A] *100*
	Winter	*Summer*	*During Hajj*	*(A)*	*Winter*	*Summer*	*During Hajj*	*(B)*	
Fuel Cost (SR/h)	152686.6	339077.3	337047.1	2392.8	153137.3	400678	398166	2748.9	14.88
CO_2 Emission (kg/h)	2088059.8	11036398.0	10972840.9	69583.2	202044	5206331	5299453.9	35807.3	48.54
NO_x Emission (kg/h)	68151.3	308328.9	306746.9	1972.2	64426.0	165229.2	167374.61	1137.2	42.34

SIMULATION RESULTS



▸▸ SIMULATION RESULTS





CONCLUSION

- This paper has discussed a case study of the application of environmental economic dispatch on the Saudi Western Operating Grid having seven thermal power plants.

- The environments constraints on CO_2 and NO_x have been considered

- It can be seen that EED leads significant reduction in the environmental pollution without any major increase in the cost

Thank You