Method for Energy Efficiency Evaluation of Coal-fired Unit Based on Environmental Protection and Reliability

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Abstract. As energy problem become more important, and nation require further intensify energy-saving work, coal-fired power plants begin to pay attention increasingly to the environmental protection and reliability. The study establishe a new method for the present coal-fired unit, that can overall evaluate environmental protection and reliability regularly. The running condition of a 600MW grade coal-fired unit in 2019 is take as an example for energy efficiency evaluation. The results prove that the method is simple andconvenient for the use. It can weigh the level of safety, energy saving, environmental protection technology and management for coal-fired power plants, and is important for advancing the firm's core competence and long-term profitability.

Keywords: Environmental Protection, Reliability, Coal-fired Unit

1 Introduction

At present, coal-fired power is the basic industry of national economy and social-cause development. The demand for coal-fired power is slow normalized growth. Power generation hour is declinefurther and the advantages of in energy-saving priority economic dispatch of the high parameter and big capacity fire power plant will gradually disappear. The fire power units, particularly coal-fired units, are under tremendous pressure to effectively run. Meanwhile, reducing pollution emissions has changed from policy support and encouragement to legally mandates. For both safey and environmental regulations, a more effective and resilien method for energy efficiency evaluation of coal-fired unit should be established in order to reasonable, full-around reflect the whole level of safety, energy-saving, environmental protection technology and management for coal-fired power plants[1]. It is important for advancing the firm's core competence and long-term profitability.

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2 The evaluation of environmental

The environmental protection of coal-fired unit consists of three subsystems: dust emission concentration, SO_2 concentration and NOx concentration. Following a thermodynamic, the weights are in order as follows: 0.2, 0.5 and 0.3. Every metric is classified into five categories: S, A, B, C, D. According to the technical route of ultra-low emission, running effect, control difficulty and impact of power consumption rate, the study rules that define S as particular matter concentration less than or equal to 1mg/Nm^3. Particular matter concentration greater than or equal to 10mg/Nm^3 is D. SO_2 concentration less than or equal to 10mg/Nm^3 is S, and greater than or equal to 35mg/Nm3 is D. NOx concentration less than or equal to 20mg/Nm^3 is S, and greater than or equal to 50mg/Nm^3 is D[2].

2.1 PM (Particular Matter) evaluation model

That particular matter evaluation method builds up triangle and semi-ladder evaluation mode. According to these statistics of particular matter concentration over the past 1 years and the standards of five level, the abscissa values and membership function is determined. PM (Particular Matter) evaluation model is shown in Fig.1.

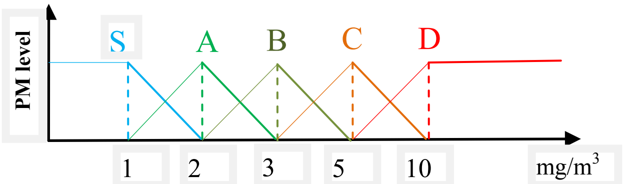

Fig. 1. PM (Particular Matter) evaluation model

The membership function of S:

$$r_{PM\to s}(PM)=\begin{cases}1 & PM\le 1\\ 2-PM & 1<PM\le 2\\ 0 & PM>2\end{cases} \tag{1}$$

The membership function of A:

$$r_{PM\to A}(PM)=\begin{cases}0 & PM<1\\ PM-1 & 1<PM\le 2\\ 3-PM & 2<PM\le 3\\ 0 & PM>3\end{cases} \tag{2}$$

The membership function of B:

$$r_{PM\to B}(PM)=\begin{cases}0 & PM\le 2\\ 1-|\ 3-PM| & 2<PM\le 5\\ 0 & PM>5\end{cases} \tag{3}$$

The membership function of C:

$$r_{PM\to C}(PM)=\begin{cases}0 & PM\le 3\\ \dfrac{PM-3}{2} & 3<PM\le 5\\ \dfrac{10-PM}{5} & 5<PM\le 10\\ 0 & PM>10\end{cases} \tag{4}$$

The membership function of D:

$$r_{PM\to D}(PM)=\begin{cases}0 & PM\le 5\\ \dfrac{PM-5}{5} & 5<PM\le 10\\ 1 & PM>10\end{cases} \tag{5}$$

2.2 NO_X evaluation model

That NOx evaluation method builds up triangle and semi-ladder evaluation mode. According to these statistics of NOx concentration over the past 1 years and the standards of five level, the abscissa values and membership function is determined. NOx evaluation model is shown in Fig.2.

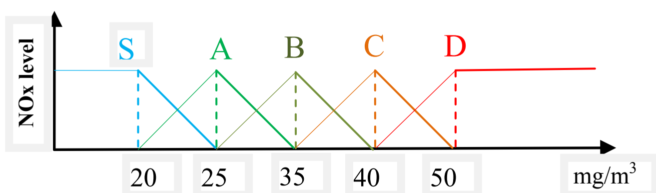

Fig. 2. NOx evaluation model

The membership function of S:

$$r_{NOx\to s}(NO_x)=\begin{cases}1 & NO_x\le 20\\ \dfrac{25-NO_x}{5} & 20<NO_x\le 25\\ 0 & NO_x>25\end{cases} \tag{6}$$

The membership function of A:

$$r_{NOx\to A}(NO_x)=\begin{cases}0 & NO_x<20\\ \dfrac{NO_x-20}{5} & 20<NO_x\le 25\\ \dfrac{35-NO_x}{10} & 25<NO_x\le 35\\ 0 & NO_x>35\end{cases} \tag{7}$$

The membership function of B:

$$r_{NOx\to B}(NO_x)=\begin{cases}0 & NO_x\le 25\\ \dfrac{NO_x-25}{10} & 25<NO_x\le 35\\ \dfrac{40-NO_x}{5} & 35<NO_x\le 40\\ 0 & NO_x>40\end{cases} \quad (8)$$

The membership function of C:

$$r_{NOx\to C}(NO_x)=\begin{cases}0 & NO_x<35\\ \dfrac{NO_x-35}{5} & 35<NO_x\le 40\\ \dfrac{50-NO_x}{10} & 40<NO_x\le 50\\ 0 & NO_x>50\end{cases} \quad (9)$$

The membership function of D:

$$r_{NOx\to D}(NO_x)=\begin{cases}0 & NO_x\le 40\\ \dfrac{NO_x-40}{10} & 40<NO_x\le 50\\ 1 & NO_x>50\end{cases} \quad (10)$$

2.3 SO_2 evaluation model

That SO_2 evaluation method builds up triangle and semi-ladder evaluation mode. According to these statistics of SO_2 concentration over the past 1 years and the standards of five level, the abscissa values and membership function is determined. NOx evaluation model is shown in Fig.3.

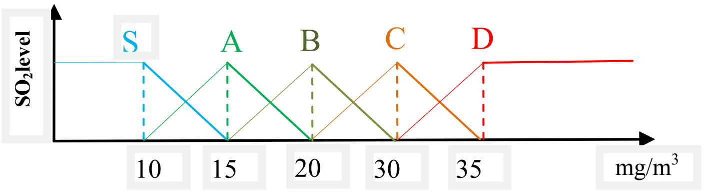

Fig. 3. SO_2 evaluation model

The membership function of S:

$$r_{SO_2\to s}(SO_2)=\begin{cases}1 & SO_2\le 10\\ \dfrac{15-SO_2}{5} & 10<SO_2\le 15\\ 0 & SO_2>15\end{cases} \quad (11)$$

The membership function of A:

$$r_{SO_2\to A}(SO_2)=\begin{cases}0 & SO_2<10\\ \dfrac{SO_2-10}{5} & 10<SO_2\le 15\\ \dfrac{20-SO_2}{5} & 15<SO_2\le 20\\ 0 & SO_2>20\end{cases} \tag{12}$$

The membership function of B:

$$r_{SO_2\to B}(SO_2)=\begin{cases}0 & SO_2<15\\ \dfrac{SO_2-15}{5} & 15<SO_2\le 20\\ \dfrac{30-SO_2}{10} & 20<SO_2\le 30\\ 0 & SO_2>30\end{cases} \tag{13}$$

The membership function of C:

$$r_{SO_2\to C}(SO_2)=\begin{cases}0 & SO_2<20\\ \dfrac{SO_2-20}{10} & 20<SO_2\le 30\\ \dfrac{35-SO_2}{5} & 30<SO_2\le 35\\ 0 & SO_2>35\end{cases} \tag{14}$$

The membership function of D:

$$r_{SO_2\to D}(SO_2)=\begin{cases}0 & SO_2\le 30\\ \dfrac{SO_2-30}{5} & 30<SO_2\le 35\\ 1 & SO_2>35\end{cases} \tag{15}$$

2.4 The environmental comprehensive evaluation model

The environmentalcomprehensive evaluation is the product of membership and weight.

$$EvB = A*R_{Ev}$$

$$=[0.2,0.5,0.30]*\begin{bmatrix} r_{NOx\to S} & r_{NOx\to A} & r_{NOx\to B} & r_{NOx\to C} & r_{NOx\to D}\\ r_{SO_2\to S} & r_{SO_2\to A} & r_{SO_2\to B} & r_{SO_2\to C} & r_{SO_2\to D}\\ r_{PM\to S} & r_{PM\to A} & r_{PM\to B} & r_{PM\to C} & r_{PM\to D}\end{bmatrix} \tag{16}$$

$$=[EvbS, EvbA, EvbB, EvbC, EvbD]$$

A is weight of particular matter, SO_2 and NOx.

3 The evaluation of reliability

The health status of coal-fired unit is evaluated by EFOR (Equivalent Forced Outage Rate)and UF(Unavailable Factor).The weights of equivalent forced outage rate and unavailable factor are respectively 0.60 and 0.40. Every metric is classified into five categories: S, A, B, C, D. The equivalent forced outage rate is calculated by formula (17):

$$EROR = \frac{FOH + (EUDH_1 + EUDH_2 + EUDH_3)}{SH + FOH + (EUDH_1 + EUDH_2 + EUDH_3)} \times 100 \tag{17}$$

FOH is Forced outage Hours; SH is Service Hours; EUDH is Equivalent Unit Derated Hours.

The unavailable factor is calculated by formula (18):

$$UF = \frac{UH}{PH} \times 100 \tag{18}$$

UH is Unavailable Hours; PH is Period Hours.

The smaller value of equivalent forced outage rate and unavailable factor, the better. The abscissa values and levels are shown in Fig.4. According to these statistics over the past 1 years, The level division goes as follows: No forced outage is S, forced outage hours monthly less than 8 is A, forced outage hours monthly less than 24 is B, forced outage hours monthly less than 72 is C, forced outage hours monthly less than 168 is D.

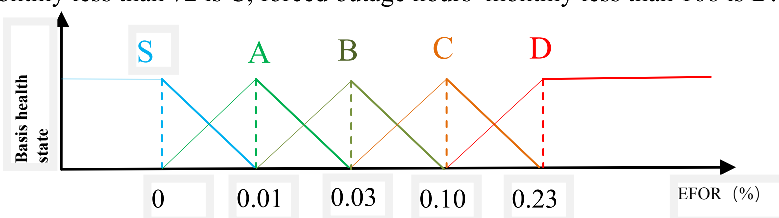

Fig. 4. Equivalent forced outage rate evaluation model

The membership function of S:

$$r_{EFOR\to s}(EFOR) = \begin{cases} 1 & EFOR \le 0 \\ \dfrac{0.011 - EFOR}{0.011} & 0 < EFOR \le 0.011 \\ 0 & EFOR > 0.011 \end{cases} \tag{19}$$

The membership function of A:

$$r_{EFOR\to A}(EFOR) = \begin{cases} 0 & EFOR < 0 \\ \dfrac{EFOR}{0.011} & 0 < EFOR \le 0.011 \\ \dfrac{0.033 - EFOR}{0.022} & 0.011 < EFOR \le 0.033 \\ 0 & EFOR > 0.033 \end{cases} \tag{20}$$

The membership function of B:

$$r_{EFOR\to B}(EFOR)=\begin{cases}0 & EFOR<0.011\\ \dfrac{EFOR-0.011}{0.022} & 0.011<EFOR\le 0.033\\ \dfrac{0.10-EFOR}{0.067} & 0.033<EFOR\le 0.10\\ 0 & EFOR>0.10\end{cases} \tag{21}$$

The membership function of C:

$$r_{EFOR\to C}(EFOR)=\begin{cases}0 & EFOR<0.033\\ \dfrac{EFOR-0.033}{0.067} & 0.033<EFOR\le 0.10\\ \dfrac{0.23-EFOR}{0.13} & 0.10<EFOR\le 0.23\\ 0 & EFOR>0.23\end{cases} \tag{22}$$

The membership function of D:

$$r_{EFOR\to D}(EFOR)=\begin{cases}0 & EFOR\le 0.10\\ \dfrac{EFOR-0.10}{0.13} & 0.10<EFOR\le 0.23\\ 1 & EFOR>0.23\end{cases} \tag{23}$$

The unavailable factor evaluation model is shown in Fig.5.

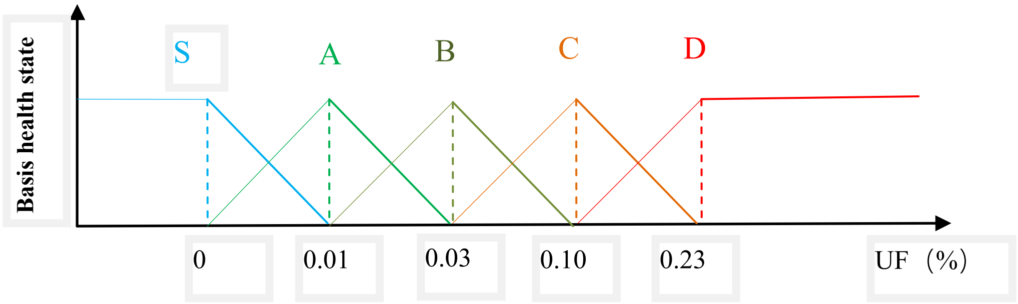

Fig. 5. The unavailable factor evaluation model

The membership function of S:

$$r_{UF\to s}(UF)=\begin{cases}1 & UF\le 0\\ \dfrac{0.011-UF}{0.011} & 0<UF\le 0.011\\ 0 & UF>0.011\end{cases} \tag{24}$$

The membership function of A:

$$r_{UF\to A}(UF)=\begin{cases}0 & UF<0\\ \dfrac{UF}{0.011} & 0<UF\le 0.011\\ \dfrac{0.033-UF}{0.022} & 0.011<UF\le 0.033\\ 0 & UF>0.033\end{cases} \tag{25}$$

The membership function of B:

$$r_{UF\to B}(UF)=\begin{cases}0 & UF<0.011\\ \dfrac{UF-0.011}{0.022} & 0.011<UF\le 0.033\\ \dfrac{0.10-UF}{0.067} & 0.033<UF\le 0.10\\ 0 & UF>0.10\end{cases} \tag{26}$$

The membership function of C:

$$r_{UF\to C}(UF)=\begin{cases}0 & UF<0.033\\ \dfrac{UF-0.033}{0.067} & 0.033<UF\le 0.10\\ \dfrac{0.23-UF}{0.13} & 0.10<UF\le 0.23\\ 0 & UF>0.23\end{cases} \tag{27}$$

The membership function of D:

$$r_{UF\to D}(UF)=\begin{cases}0 & UF\le 0.10\\ \dfrac{UF-0.10}{0.13} & 0.10<UF\le 0.23\\ 1 & UF>0.23\end{cases} \tag{28}$$

4 The comprehensive evaluation model of environmental protection and reliability

The weights of environmental protection and reliability are respectively 0.60 and 0.40.

$$B_{CD}=A*RES$$

$$=[0.60,0.40]*\begin{bmatrix}Evb_S & Evb_A & Evb_B & Evb_C & Evb_D\\ Dev_S & Dev_A & Dev_B & Dev_C & Dev_D\end{bmatrix} \tag{29}$$

$$=[Cd_S, Cd_A, Cd_B, Cd_C, Cd_D]$$

5 The evaluation of results

The running condition of a 600MW grade coal-fired unit in 2019 is take as an example for energy efficiency evaluation. These statistics are shown in Table 1.

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Table 1. The running statistics in 2019

Name	Unit	January	February	March	April	May	June
NOx	mg/Nm^3	18.48	28.91	33.11	32.23	33.76	38.13
SO_2	mg/Nm^3	5.55	8.85	8.6	8.8	10.51	7.99
PM	mg/Nm^3	0.57	0.7	0.76	0.8	0.6	0.46
FOH	h	0	0	0	0	0	0
SH	h	744	696	744	720	744	720
EUDH	h	0	0	0	0	0	0
UH	h	0	0	0	0	0	0
Spare hour	h	0	0	0	0	0	0
Name	Unit	July	August	September	October	November	December
NOx	mg/Nm^3	36.01	31.78	30.66	30.46	28.58	23.06
SO2	mg/Nm^3	8.38	9.51	11.17	10.65	9.84	13.18
PM	mg/Nm^3	0.48	0.57	0.91	1.02	0.75	0.69
FOH	h	0	0	0	0	0	0
SH	h	744	744	720	744	720	744
EUDH	h	0	0	0	0	0	0
UH	h	0	0	0	0	0	0
Spare hour	h	0	0	0	0	0	0

The evaluation results of environmental protection and reliability are shown in Table 2.

6 Conclusion

The results show the energy efficiency level of the 600MW grade coal-fired unitis is high in 2019. The results are S for every month. The method is simple and convenient for the use. It can weigh the level of safety, energy saving, environmental protection technology and management for coal-fired power plants, and it is beneficial upgrade the management level and safety reduce costs to coal-fired unit.

References

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Table 2. The evaluation results of environmental protection and reliability

Name		PPM	SO_2	NO_X	Environmental protection	EFOR	UF	Reliability	Comprehensive evaluation model of environmental protection and reliability	Result
Weights		0.2	0.5	0.3		0.6	0.4			
					0.6			0.4		
January	Value	0.57	5.55	18.48		0	0			
	S(λ)	1	1	1	1	1	1	1	1	S
	A(λ)	0	0	0	0	0	0	0	0	
	B(λ)	0	0	0	0	0	0	0	0	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
February	Value	0.7	8.85	28.91		0	0			
	S(λ)	1	1	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0.609	0.1827	0	0	0	0.10962	
	B(λ)	0	0	0.391	0.1173	0	0	0	0.07038	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
March	Value	0.76	8.6	33.11		0	0			
	S(λ)	1	0	0	0.7	1	1	1	0.82	S
	A(λ)	0	0.2	0.189	0.0567	0	0	0	0.03402	
	B(λ)	0	0.8	0.811	0.2433	0	0	0	0.14598	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
April	Value	0.8	8.8	32.23		0	0			
	S(λ)	1	0	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0.277	0.0831	0	0	0	0.04986	
	B(λ)	0	0.94	0.723	0.2169	0	0	0	0.13014	
	C(λ)	0	0.06	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
May	Value	0.6	10.51	33.76		0	0			
	S(λ)	1	0.898	0	0.649	1	1	1	0.7894	S
	A(λ)	0	0.102	0.124	0.0882	0	0	0	0.05292	
	B(λ)	0	0	0.876	0.2628	0	0	0	0.15768	

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	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
June	Value	0.46	7.99	38.13		0	0			
	S(λ)	1	1	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0	0	0	0	0	0	
	B(λ)	0	0	0.374	0.1122	0	0	0	0.06732	
	C(λ)	0	0	0.626	0.1878	0	0	0	0.11268	
	D(λ)	0	0	0	0	0	0	0	0	
July	Value	0.48	8.38	36.01		0	0			
	S(λ)	1	1	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0	0	0	0	0	0	
	B(λ)	0	0	0.798	0.2394	0	0	0	0.14364	
	C(λ)	0	0	0.202	0.0606	0	0	0	0.03636	
	D(λ)	0	0	0	0	0	0	0	0	
August	Value	0.57	9.51	31.78		0	0			
	S(λ)	1	1	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0.322	0.0966	0	0	0	0.05796	
	B(λ)	0	0	0.678	0.2034	0	0	0	0.12204	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
September	Value	0.91	11.17	30.66		0	0			
	S(λ)	1	0.766	0	0.583	1	1	1	0.7498	S
	A(λ)	0	0.234	0.434	0.2472	0	0	0	0.14832	
	B(λ)	0	0	0.566	0.1698	0	0	0	0.10188	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
October	Value	1.02	10.65	30.46		0	0			
	S(λ)	0.98	0.87	0	0.631	1	1	1	0.7786	S
	A(λ)	0.02	0.13	0.454	0.2052	0	0	0	0.12312	
	B(λ)	0	0	0.546	0.1638	0	0	0	0.09828	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
November	Value	0.75	9.84	28.58		0	0			
	S(λ)	1	1	0	0.7	1	1	1	0.82	S
	A(λ)	0	0	0.642	0.1926	0	0	0	0.11556	

	B(λ)	0	0	0.358	0.1074	0	0	0	0.06444	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	
December	Value	0.69	13.18	23.06		0	0			
	S(λ)	1	0.364	0.388	0.4984	1	1	1	0.69904	S
	A(λ)	0	0.636	0.612	0.5016	0	0	0	0.30096	
	B(λ)	0	0	0	0	0	0	0	0	
	C(λ)	0	0	0	0	0	0	0	0	
	D(λ)	0	0	0	0	0	0	0	0	