Reliability Aspect of Application of DDC Computer in Power Plants

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Abstract

The subject of this paper is the reliability aspect of the application of DDC computer systems in thermal and nuclear power plants. The influence of the computer's Mean Time to Failure and Mean Time to Repair on a power plant's economic outage penalty cost has been investigated, and the total economical losses during the economical power plant life have been calculated for various economical factors.

1. Introduction

Although the application of on-line computers for data acquisition in thermal and nuclear power plants has become unquestionable, their use for Direct Digital Control (DDC) is still being discussed[1]. Jervis[2] analyses this problem in England's electrical power system. He contends that the application of DDC computers in nuclear power plants with gas cooled reactors is economically attractive, and there are already examples of such approaches to the power plants' automation. Obviously, it involves high reliability requirements of the computer, although in the case of thermal power plants there is little incentive to invest capital to improve the computer reliability.

Nevalaimen[4] discusses the hypothetical application of a DDC computer in a power plant with a BWR (Boiling Water Reactor). He has investigated the optimal configuration of the DDC computer and back-up control instrumentation. He assumes two methods for the calculation of power plant outage losses: discounting and absolute. These methods involve quite a different optimal solution of the control equipment. The optimal solution also depends on the assumed Mean Time to Repair of the computer's components.

It is known that some of the power plant analog control systems have become very complicated in order to fulfil the requirements of high quality control in a

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wide range of the unit's load. Examples of this would be the steam temperature control of thermal power plants, or the fuel elements' temperature distribution control in a nuclear reactor. Such no-standard control systems can have lower reliability parameters than the DDC computer system. In the near future, the majority of thermal power units will have to be following the power system load curve, and be characterized by a quick response during considerable load changes. The application of the DDC computers in thermal plants will become very attractive, because the modern control theory and optimization methods have been introduced in a natural manner. An interesting example of the so called inverse response control, which combines the merits of the analog control loops and the computer system, is described in 3).

For the reason mentioned above, the application of DDC control in nuclear power plants seems to be already attractive. According to 2), the cost of nuclear plant automation doesn't depend significantly on the design approach - neither with a DDC computer nor with a conventional instrumentation. There is wide usage of the on-line computer for data acquisition in both nuclear and thermal power plants, and it is quite natural to ask to which level their reliability can be imporved so that a DDC computer could be adapted, and how much it will cost.

2. Notation

UCO : unit capacity - oil fired power plant, MW
UCA : unit capacity - atomic power plant, MW
CFO : capacity factor - oil fired power plant
CFA : capacity factor - atomic power plant
IRA : interest rate
CRO : cost of energy conversion - oil fired power plant, dollar/MWh
CRA : cost of energy conversion - atomic power plant, dollar/MWh
RIO : annual factor of the energy conversion cost increase - oil fired power plant
RIA : annual factor of the energy conversion cost increase - atomic power plant
RDO : restart delay - oil fired plant, hour
RDA : restart delay - atomic power plant, hour
EPL : economical plant life, year
MTF : mean time to failure, hour
MTR : mean time to repair, hour
(A)OCO(D) : (annual) outage costs (discounted) - oil fired power plant, dollar
(A)OCA(D) : (annual) outage costs (discounted) - atomic power plant, dollar

3. Calculation of the power plant economic outage penalty

It is known that the operating cost of electrical energy production in modern nuclear power plants is considerable lower than in thermal power plants. (On the contrary, the investment cost per unit of plant capacity is higher.) The shut down of a big nuclear plant will make it necessary to replace cheap electrical energy by more expensive energy derived from thermal power plants. The outage of a big thermal power unit, on the other hand, will make it necessary for the less economical thermal power plants to be used instead of the shut-down capacity. In both cases, it will be partly possible to get shut-down capacity by an increase of the output of the power of hydro power units, and sometimes a reserve thermal unit will be necessary. The estimation made for a certain power system shows that the costs of electrical energy conversion (CRA or CRO), assuming the present operating costs of power plants, are around 25 dollars/MWh in the case of outages of modern nuclear power plants, and around 5 dollars/MWh in the case of outages of modern oil fired power plants. In the future, CRA and CRO will increase continuously because of foreseen increases of fuel prices.

The discounted penalty cost of the nuclear power plant outages during the economical plant life (EPL) can be expressed as follows.

$$\mathrm{OCAD} = \sum_{I=1}^{EPL} (8760/\mathrm{MTF})\ \mathrm{UCA}.\ \mathrm{CFA}\ (I).\ \mathrm{CRA}\ (I).\ (\mathrm{MTR}+\mathrm{RDA}).\ (1+\mathrm{IRA})^{-I} \tag{1}$$

In our calculation, the economical penalty cost has been discounted to year 0 (the first calendar year of the unit's operation after commissioning). In such a case, the discounting factor in year I equals[5] $(I+\mathrm{IRA})^{-I}$.

The annual outage cost in year '0' equals

$$\mathrm{AOCA}\ (0) = (8760/\mathrm{MTF}).\ \mathrm{UCA}.\ \mathrm{CFA}\ (0).\ \mathrm{CRA}\ (0).\ (\mathrm{MTR}+\mathrm{RDA}) \tag{2}$$

If it is assumed the CFA(I) to be constant, and the value of I to be between 1 and EPL, the energy conversion cost will increase continuously with the factor $(1+\mathrm{RIA})^{I}$, and the non-discounted economical penalty cost of the plant outage will be

$$\mathrm{OCA}\ (1, \mathrm{EPL}) = \mathrm{AOCA}\ (0).\sum_{I=1}^{EPL}(1+\mathrm{RIA})^{I} \tag{3}$$

and with discounting

$$\mathrm{OCAD}\ (1, \mathrm{EPL}) = \mathrm{AOCA}\ (0).\sum_{I=1}^{EPL}\{(1+\mathrm{RIA})/(1+\mathrm{IRA})\}^{I} \tag{4}$$

The equations were assumed to be identical in the case of the outages' penalty

Table 1. Outage Costs Oil Fired Power Plant
UCO=600MW, EPL=25 years, IRA=0.08

MTF	MTR	AOCO	RIO=0.0		RIO=0.025	
			OCO	OCOD	OCO	OCOD
1000	1	39400	985000	421000	1380000	536000
2000		19700	493000	210000	690000	268000
4000		9900	246000	105000	345000	134000
8000		4900	123000	53000	173000	67000
1000	4	98600	2664000	1052000	3450000	1339000
2000		49300	1232000	526000	1725000	670000
4000		24600	616000	263000	863000	335000
8000		12300	308000	132000	431000	167000
1000	8	197000	4927000	2104000	6901000	2679000
2000		99000	2464000	1052000	3450000	1339000
4000		49000	1232000	526000	1725000	670000
8000		25000	616000	263000	863000	335000

Table 2. Outage Costs Atomic Power Plant
UCA=600MW, EPL=25 years, IRA=0.08, RDA=5 hours

MTF	MTR	AOCA	RIA=0.0		RIA=0.030	
			OCA	OCAD	OCA	OCAD
2000	1	142000	3548000	1515000	5329000	2030000
4000		71000	1774000	757000	2665000	1015000
8000		35000	887000	379000	1332000	507000
16000		18000	443000	189000	666000	254000
2000	4	213000	5322000	2272000	7994000	3044000
4000		106000	2661000	1136000	3997000	1522000
8000		53000	1330000	568000	1998000	761000
16000		27000	665000	284000	999000	380000
2000	8	307000	7687000	3282000	11546000	4397000
4000		154000	3843000	1641000	5773000	2199000
8000		77000	1922000	821000	2887000	1099000
16000		38000	960000	410000	1443000	550000

of an oil fired power plant.

In the calculations, the following values of parameters were assumed: IRA=0.08, RIA=0.03, RIO=0.025, EPL=25 or 30 years, MTF=1000–32000 hours, MTR=1–32 hours, UCO=UCA=400–1000MW, RDA=5 hours, RDO=1 in the case of MTR$\leqq$5 hours and RDO=2 in the case of MTR$>$5 hours.

Table 3. Dicounted Outage Costs of a Oil Fired and a Nuclear Power Plant
UCO=UCA=600MW, MTR=2 HOURS, RIO=0.025, RIA=0.030

EPL		MTF			
		2000	4000	8000	16000
25	OCOD	402000	201000	100000	50000
30		436000	218000	109000	55000
25	OCAD	2368000	1184000	592000	296000
30		2588000	1294000	647000	323000

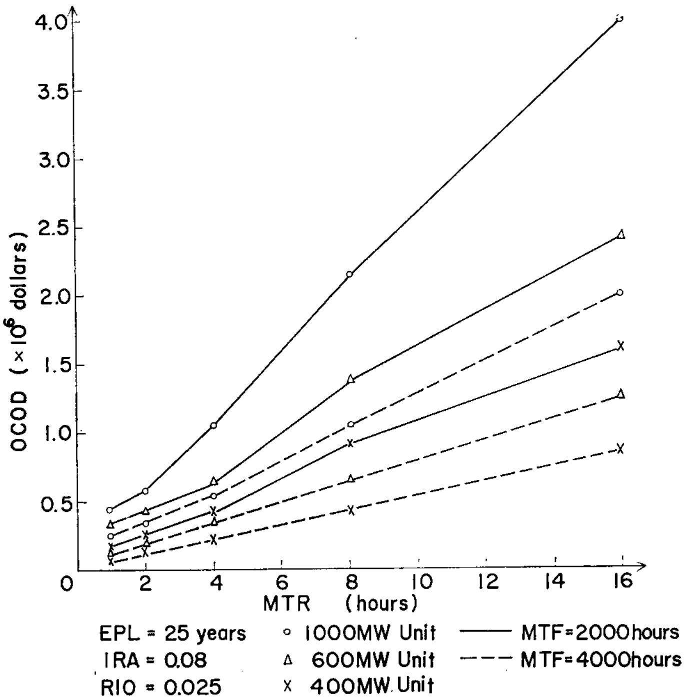

Fig. 1. Discounted Outage Costs of Oil Fired Power Plants.

The results of the calculations are presented in Tables 1,2,3, and in Figures 1 and 2.

4. Discussion

Tables 1 and 2 show that the discounted penalty cost of the power plant outage is less than 50 % of the absolute cost. If such a the method of discounting assumes that the computer system reliability requirement will be somewhat reduced, the back-up control instrumentation is expected be different from the absolute cost method.

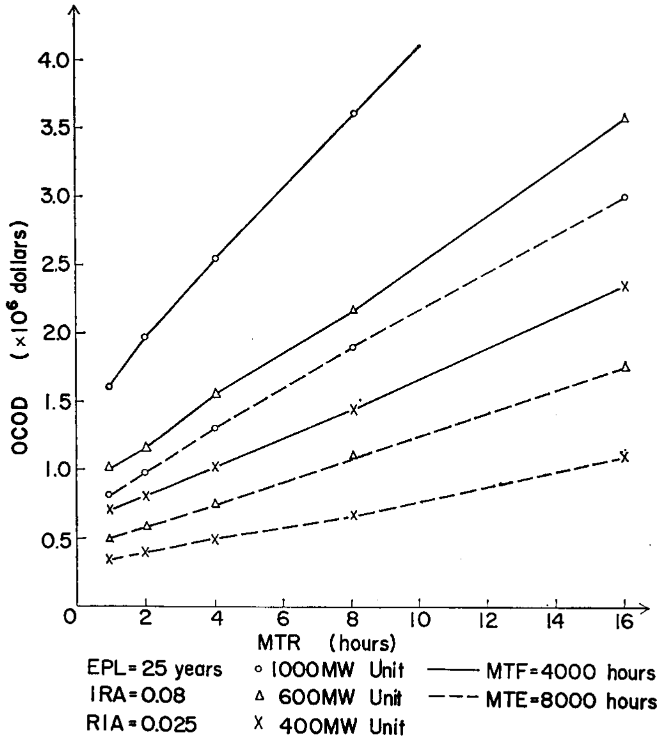

Fig. 2. Discounted Outage Costs of Oil Fired Power Plants.

The influence of the computer's Mean Time to Repair on the penalty cost is obvious, and it can be seen from Tables 1 and 2 that a highly reliable DDC computer, but with out good repair characteristics, can be less valuable than a computer with less reliability but very good repair properties.

The assumption that the EPL value equals 25 or 30 year makes approximately a 9 percent difference in the results. (Table 3) More visible is the influence of RIO and RIA. For instance, at RIA=0.03, the difference in the results is about 30 % in the case of discounted costs, and about 50 % the case of non discounted costs. (Table 2) It is obvious that the economic penalty cost of outages according to the assumed model is proportional to the unit capacity. (Figs. 1 and 2)

The obtained data permit decisions about the DDC computer system configuration and the extentions of the back-up control instrumentation. (The back-up instrumentation must be able to do a safe plant shut-down, and eventually a plant 'freezing' operation.) The computer cost analysis shows[4] that the cost of a single processor computer system is expected to be, at present, about 1,400,000 dollars (including software and hardware). The cost of a double processor computer is expected to be about 1,800,000 dollars. It can be shown that this aditional investment cost of 400,000 dollars increases the computer's M.T.F. (Mean Time to Failure) by at least four times. If we assume that the MTF of a single processor computer equals 2000 hours, it will be noticed (Table 2, MTR=1, RIA=0.03) that it is posible to save at least one million dollars during the life of a 600 MW nuclear power plant. In the case of a 600 MW oil fired power plant, the application of a redundant computer system is not clearly substantial. (Table 1, MTR=1 hour)

The application of a DDC computer system can not decrease the safety of a power plant. It means that the power plant protection philosophy should remain unchanged.

The designers'decision about a DDC computer application in a power plant's automation is dependent on many technical and economical factors. The outline of a simplified economical analysis is presented in Table 4.

Table 4. Outline of a simplified economical analysis of DDC computer applications

Ai		Expenses and Savings	Bi		Economical advantages and Losses
1	+	cost of high reliability computer system	1	+	economical advantage of DDC application
2	−	cost of hypothetical computer for data acquisition	2	−	economical penalty of DDC failures
3	−	cost of reduced conventional control instrumentation	3	+	economical penalty of failures of hypothetical conventional control instrumentation
4	+	cost of back-up instrumentation			
5	−	cost of man power			

If $\sum Bi > \sum Ai$, a DDC application will be economically attractive. The factors of analysis should be considered during the plant life and discounted for an assumed year.

The economical advantages of a DDC application can be divided into two groups.

1. Associated with the electrical power system operation.
2. Associated with direct power plant operation.

For instance, an improvement of the thermal power plant dynamical characteristics will allow a substantial saving of investment capital for new power plants.

An example of the second group advantage could be the improvement of the steam temperature control of a super-critical boiler, which will decrease the steam temperature's dispersion. This, in turn, will increase the superheater's Mean Time to Failure. The merits of DDC during plant start-up are especially important in the case of under-super-critical units.

5. Conclusion

The investigation of a power plant's outage penalty costs allowed us to solve the DDC computer reliability allocation problem, and the extension of the back-up control instrument. However, a proper method of power plant economical outage penalty cost has to be assumed. The method of absolute cost analysis gives a significant difference, compared with the method of discounting cost, and it will influence the optimal reliability allocation. It is also important to consider the increase of future energy conversion costs.

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