

CALCULATIONS OF THE CONTROLLER LOAD IN COMPUTER CONTROL NETWORK USING PROBABILITY THEOREM

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(Received September 17, 2008 Accepted October 29, 2008)

This paper presents the calculation of the controller load of computer control network in a real system. The Calculation of the controller load is very important in order to aid the designer engineer to choose the suitable capacity of the controller for data size. The probability theorem is used to investigate the process of load calculation. The interpolation technique is used to get the function of the required data for the studied system. The calculated value is compared with the measured value to investigate the reality of the proposed method in calculating the load controller using probability theorem. The comparative study between the measured value and calculated value indicate the efficiency of the proposed technique.

KEYWORDS: *Distributed Control System – Controller Load – Probability Theorem.*

1. INTRODUCTION

In recent years the computer control technology has developed greatly with the rapid enhancement. The development of the computer technologies reflects to other fields such as control theory and data communication network. The main stream is so called distributed control systems, DCS. Since **1970s the DCS** has been used widely in industry, in many applications [1-4]. The distributed control system, DCS has a different data forms such as analog input, analog input calculated, analog output, analog out calculated, digital input, digital input calculated and digital output [5]. The data come from the field all has one of the previous forms to the controller sub-rack then through a communication to the controller rack. These data will be processed on the processor according to the required functions, subjected to the software program. Let's go through to explain briefly the field data which applied to the controller.

2. CONTROLLER LOAD CALCULATIONS

The controller load is monitored as a percentage from the total capacity of the controller. The capacity of the controller is measured and calculated as bits/sec for the

same studied high dam controller system. In order to calculate the load of the controller in this paper, this should be done on the high dam network as a life network. The data of this network as analog, digital or events will be used in load calculation. Being these data have a different forms and the system is working hot all the time, it should be subjected to the probability theorem in the dynamic part of the controller load. Finally the load of the high dam controller will be calculated according to the high dam data base dynamics.

2.1 General Controller (CPU) Load Equations

For the controller used in the computer control network such as power stations, production lines in the factories, and a unified power system, the load consists of static part and dynamic part. But in the telephone system as example the load is only the subscriber's requests and it is considered as a dynamic load, beside the internal activities of the CPU. In the control network there are many data forms. The forms of data in control network are:

- AI (analog input)
- AIC (analog input calculated)
- AO (analog output)
- AOC (analog output calculated)
- DI (digital inputCyclic or interrupt)
- DIC (digital input calculated)
- DOC (digital output calculated)

Based on these data we can estimate a formula for the controller (CPU) load used in the control fields through, distributed control system, DCS networks.

These types of the controllers are subjected to static load which will be determined from specification's tables supplied by the manufacturers. These tables are shown in Appendices A,B for the studied system of the controller used in the high dam power plant computer network. This controller is ABB made with a module name (AC450).

The static load is subjected to a certain scan time which should be optimized to give a stable performance. The base load has a fixed value according to manufacture's instructions. But the dynamic load is referred to the system dynamics and data activities applied to the controller.

The load of the controller contains briefly 3 parts:

- 1- The load used to cover the controller internal activities named the base load.
- 2- The static load due to the scanning process of the data designed through the software.
- 3- The dynamic load due to data variations, system dynamics and operator requests.

The load of the controller can be expressed in the following form.

$$\text{Load} = \text{base load} + \text{static load} + \text{dynamic load} \quad (1)$$

2.2 Static Load Calculations

The static load will be calculated using the tables in the appendices A, B below. It is calculated for A_i, AIC, A_o, DIC, and Do. These data base are explained in details above.

2.3 Analog Input (AI) Static Load

From the appendices A, B the analog input data base element can be summarized in the following tables. This can be seen from the sequence of the calculations mentioned in appendices A, B.

Table (1) analog input load calculation

serial	program	NO of data	Scan time (ms)	service time (ms)	Load %	sum
1	PC1.1	8	50	0.2	3.2	
2	PC4.4	13	50	0.2	5.2	
3	PC14.1	40	200	0.2	4	
4	PC31.4	99	500	0.2	3.96	
5	PC32.1.4	56	500	0.2	2.24	
6	PC54.1	111	500	0.2	4.44	
7	PC54.3	116	500	0.2	4.64	
8						27.68

2.4 Analog Input Calculated Static Load

Using the appendices A, B and data base movements, the calculations appear in Table 2. This table depicts the load for each PC then all items should be summed to give the total load.

Table (2) Analog input calculated load

serial	program	No of data	Scan time (ms)	service time (ms)	Load %	sum
1	PC3.2	39	200ms	0.003	.0585	
2	PC4.1	74	200ms	0.003	0.111	
3	PC4.2	40	200ms	0.003	0.06	
4	PC4.3	0	200ms	0.003	0	
5	PC31.1	66	500ms	0.003	0.0396	
6	PC31.4	83	500ms	0.003	0.0498	
7	PC32.1	83	500ms	0.003	0.0498	
8	PC52.1	83	500ms	0.003	0.0498	
9	PC54.3	81	500ms	0.003	0.0486	
10						0.467

3.5 Analog Output Static Load

The same procedure of section (3.3), (3,4) is also used to calculate the load of analog output and the results appear in Table 3.

Table (3) analog output static load

serial	program	No of data	Scan time (ms)	service time (ms)	Load %	sum
1	PC4.5.1	13	200ms	0.02	0.13	
2						0.13

2.6 Digital Input Calculated Static Load

Table (4) shows the static load of the digital input calculated using the same procedure from appendices A, B.

Table (4) digital input calculated static load

serial	Program	No of data	Service time(ms)	Scan time(ms)	Load%	sum
1	PC2.1	36	0.003	50ms	0.216	
2	PC4.1,2	51	0.003	200ms	0.0765	
3	Pc32,PC54	44	0.003	500ms	0.0264	
						0.32

2.7 Digital Output Static Load

The digital output static load results can be calculated using same procedure as shown in Table (5).

Table (5) digital output static load

serial	Program	NO of data	Scan time (ms)	service time(ms)	Load %	sum
1	PC1.9.2	34	200ms	0.003	0.05	
2	PC52.1	16	500ms	0.003	0.0096	
3						0.0596

Note that the data base elements D_1 , DOC, AOC can't be calculated because D_1 (digital input) in the studied system high dam control network is specified as interrupt; this means it will be applied to the controller when it changes its position. For the DOC and AOC are not found in the high dam control network.

2.8 Total Static Load

The total static load = $27.68 + 0.467 + 0.13 + 0.32 + 0.0576 = 28.65 \%$

2.9 Dynamic Load Calculations

As mentioned above the dynamic load is raised from the system dynamics like starting of the generators, load increase, load decrease, and switch on/off of the breakers also the operator screen requests. In order to calculate the dynamics of the control system we have to consider the probability theory and probability functions as the following sections.

3. PROBABILITY THEOREMS FOR CONTROLLER INPUT SIGNALS

The nature of the data applied to the controller in the control system is:

- Continuous data form (analog)
- Discrete data form (Digital)

For the discrete data base the following mathematical formulas will be used to calculate the probability for digital signals are:

3.1 Discrete signals

$$F(x) \geq 0 \tag{2}$$

$$\sum_x F(x) = 1 \tag{3}$$

The equation for discrete (digital) signals in a certain time period will be:

$$P_n = (\lambda t)^n * e^{-\lambda t} / n! \tag{4}$$

Where; P_n = Digital input probability (discrete) in a certain period of time (t).

Based on the above equations the probabilities of the discrete data base can be calculated as the following.

Let P(t) be the probability of one count in time t, so that P(t+Δt) is the probability of one count in time t+Δt Now we will have one count in time t+Δt in the following two mutually exclusive cases:

- (i) 1 count in time t and 0 counts in time Δt
- (ii) 0 counts in time t and 1 count in time Δt

The probability of (i) is P₁(t)(1-(tΔt)

The probability of (ii) is P₀(t) Δt.

Thus, apart from terms involving (Δt)² and higher.

$$P_1(t + \Delta t) = P_1(t)(1 - \lambda \Delta t) + P_0(t)\lambda \Delta t \tag{5}$$

This can be written

$$P_1(t + \Delta t) - P_1(t) / \Delta t = \lambda - \lambda P_1(t) \tag{6}$$

Taking the limit as Δt → 0 and using the expression for P₀(t) = e^{-λt}

So: $\frac{d P_1}{dt} = \lambda e^{-\lambda t} - \lambda P_1$ (7)

Or

$$\frac{d p_1}{dt} = \lambda e^{-\lambda t} - \lambda P_1$$

$$\frac{d p_1}{dt} + \lambda P_1 = \lambda e^{-\lambda t} \tag{8}$$

Multiplying by e^{-λt} this can be written

$$\frac{d}{dt} (e^{\lambda t} P_1) = \lambda \tag{9}$$

Which yields on integrating

$$P_1(t) = \lambda t e^{-\lambda t} + c_2 e^{-\lambda t} \tag{10}$$

If t=0, P₁(0) is the probability of 1count in time 0, which is zero. Using this in equation (10) we find c₂=0. Thus

$$P_1(t) = \lambda t e^{-\lambda t} \tag{11}$$

By continuing in this manner we can show that the probability of n counts in time t is given by:

$$P_n(t) = (\lambda t)^n * e^{-\lambda t} / n! \quad (12)$$

This is the Poisson distribution.

The discrete data probability can be calculated using also the following formula.

$$\text{Probability} = \lambda / N \quad (13)$$

Where:

- λ = number of events
- N = sample space

3.2 Analog Input Probability

Matlab tools is used to evaluate the continues data probability

The formulas used in continues data evaluation are:

$$F(X) \geq 0 \quad (14)$$

$$\int_{-\infty}^{\infty} F(X) dx = 1 \quad (15)$$

So the probability between (a, b) limits will be expressed by the following equation.

$$P(a < X < b) = \int_a^b F(X) dx \quad (16)$$

The general equation for continues probability (analog input) and (analog input calculated) can be derived [7].

$$P(a < xb) = C * \int_b^a f(x) dx = C [f(b) - f(a)] \quad (17)$$

Where:

$$C * f(x) = 1$$

3.3 Probability Calculations

The above equations (12), and (17) are solved by Matlab software to find both the discrete and continues data base probability of the studied system. The final results are shown in Table (6).

3.3.1 Continuous signals

To calculate the probability of continues signals the Matlab software is used with the following steps.

- 1- The signal will be displayed as a trend from the DCS system.
- 2- Some points of coordinates should be located to represent the trend behavior of the analog element.

- 3- From the coordinates the equation of the trend can be derived using the function (polyval) in matlab.
- 4- The resulted function for polynomial should be integrated.
- 5- Using the above functions the probability can be calculated.
- 6- For accuracy the probability will be calculated for a different cases and the mean value should be calculated.

3.3.2 Discrete signals

For discrete (digital input) signal, equation (12) which stated below as equation (18) should be used. The calculation of the probability will be carried out through matlab program using the following equation.

$$P_n = (\lambda t)^n * e^{-\lambda t} / n! \quad (18)$$

Where:

- P_n = probability of the discrete signals.
- λt = constant times the time sample space.
- n = number of signals.

3.3.3 Digital output probability:

The digital output probability can be calculated from the field counts let's go to have a look on the counts at the point of the high events, that means during the generator start, generator stop and auxiliaries

The events will be as flows:

- 1- Generator start sequence=7
- 2- Generator stop sequence =10
- 3- Auxiliaries operation. = 6

Total number of events = 7+10+6 = 23

Since probability $P = \lambda/N = 23/76 = 0.302$

Where: λ = number of events, N = sample space or total number of data base signals.

3.3.4 Digital input calculated.

The counting of digital input calculated signal also can be done from the field for the max point of load (start/stop) sequences of the generator the result will be as follows:

- 1- Standstill, on-line and stop enables (indication) =6.
- 2- Unit standstill, ready for synchronize and on-line (working mode) = 6
- 3- High pump on high pressure >50 bar (indication) = 4
- 4- Governor 4x-R-0, G P S (7% and 0%) working mode = 8
- 5- Unit circuit breaker on/off (working mode) =2
- 6- MG field switch on/off and Aux AVR off (working mode) =3

Total events of DIC =6+6+4+8+2+3 = 29 events

The probability $P = \lambda/N = 29/58 = 0.5$

The total results of the probability seen in table (6) below

Table (6) calculated probability

serial	Data base name	probability
1	AI	0.461
2	AIC	0.403
3	Ao	0.321
4	DI	0.0327
5	DIC	0.50
6	Do	0.302
7	AOC	-----
8	DOC	-----

3.3.5 Dynamic load equation estimation:

To estimate the dynamic load we have to refer to the probability theorems.

Dynamic load =

$$P_{AI} * N_1 * T_1 + P_{AIC} * N_2 * T_2 + P_{AO} * N_3 * T_3 + P_{AOC} * N_4 * T_4 + P_{DI} * N_5 * T_5 + P_{DIC} * N_6 * T_6 + P_{DO} * N_7 * T_7 + P_{DOC} * N_8 * T_8 \tag{19}$$

Where:

- P's= are probabilities for the different data base forms.
- N's = number of data base elements for each kinds
- T's = the service time's

3.3.6 Dynamic load calculation:

To solve equation of the dynamic load, let's consider the DCS system of the high dam power plant which use (AC450) controller, ABB manufacturing.

The dynamic load formula is as the following:

$$\text{Load (dynamic)} = P * N * T \tag{20}$$

Where: P= probability, N= number of data base, T= service time.

The following table (7) shows the number of data base and the corresponding service time.

Table (7) service time and number data elements

Serial	Data base	Number of data base	Service time
1-	AI	182	0.15
2-	AIC	83	0.08
3-	AO	15	0.18
4-	DI	384	0.6
5-	DIC	58	0.05
6-	DO	76	0.13
7-	AOC	-----	-----
8-	DOC	-----	-----

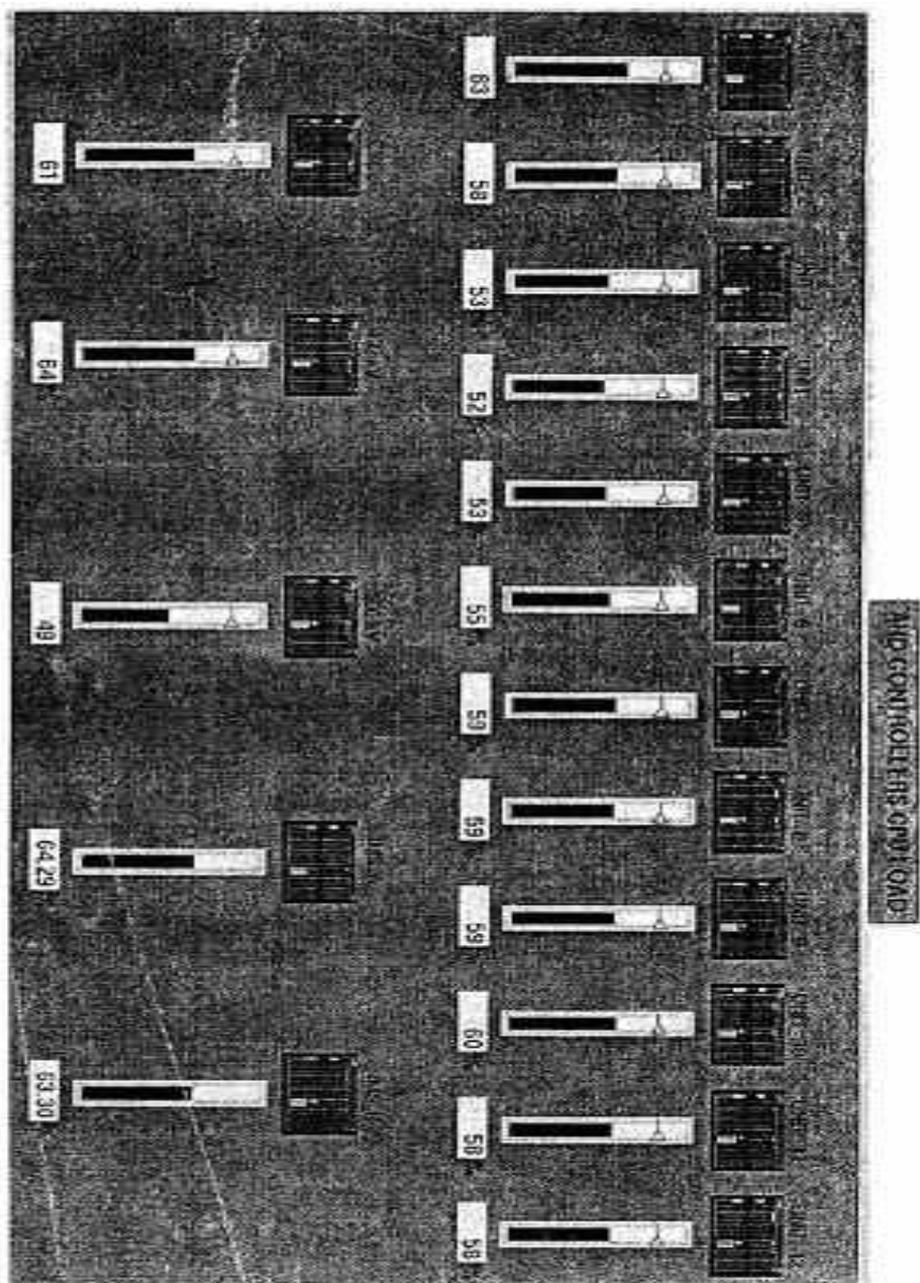


Fig. 1 The measured load of the controller for high dam

3.3.7 Calculations of dynamic signals

- 1- $AI = 0.461 \cdot 182 \cdot 0.15 = 12.585$
- 2- $AIC = 0.403 \cdot 83 \cdot 0.08 = 2.676$
- 3- $A_0 = 0.321 \cdot 15 \cdot 0.18 = 0.867$
- 4- $DI = 0.0327 \cdot 0.6 \cdot 384 = 7.534$
- 5- $DIC = 0.5 \cdot 0.05 \cdot 58 = 1.45$

$$6- D_o = 0.302 * 0.13 * 76 = 2.98$$

Total dynamic load = 28.1

Base load = the value taken for our analysis is 2 from the controller features.

Static load = 34.875% calculated using ABB instruction manuals.

Load total = 2% + 28.65% + 28.1% = 58.75%

This load value should be < 80%

The measured value of the controller load for the high dam power station is as shown in Fig. 1.

4. CONCLUSIONS

This paper presents the implementations of the probability theorem to calculate the dynamic load of the controller in a distributed control system for HIGH DAM in Aswan.

The measured value of the controller load in the studied real system of the High dam power station as shown in Fig. 1 is used to judge the efficiency of the proposed method. The probability theorem is used to calculate the controller dynamic load. The mathematical interpolation is used to derive the function of the trends coming out from the information management system of the high dam computer controller network. The Matlab software is used for the calculation of the controller dynamic load based probability theory. The comparative studies between the measured and calculated values indicate the efficiency of the proposed method in the calculation of the controller load of the studied real system. These encourage using the proposed method for calculating the dynamic load of the controller for any DCS.

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Appendix (A)

*Advant® Controller 450 User's Guide
Load Calculation Forms*

Load Calculation

Load Calculation Forms

Table Calculation of CPU-load from S100 and S800 Inputs

Signal type	No of signals	Basic load (ms)	Scan time (ms)	Dynamic load (ms)	Changes/sec. per signal	Total load
AI	A)	B) 0.20	C) _____ ms E)=100*A*B/C E) _____ %	F) 0.15	G) _____ H)=A*G*F/10 H) _____ %	E+H _____ %
AIC	A)	B) 0.003	C) _____ ms E)=100*A*B/C E) _____ %	F) 0.08	G) _____ H)=A*G*F/10 H) _____ %	E+H _____ %
DI cycl.	A)	B) 0.20/board D) _____ ch/board	C) _____ ms E)=100*A*B/C/D E) _____ %	F) 0.05	G) _____ H)=A*G*F/10 H) _____ %	E+H _____ %
DI interr.	A)			F) 0.60	G) _____ H)=A*G*F/10 H) _____ %	E+H _____ %
DIC	A)	B) 0.003	C) _____ ms E)=100*A*B/C E) _____ %	F) 0.05	G) _____ H)=A*G*F/10 H) _____ %	E+H _____ %
Total						_____ %

Appendix (B)

Advant[®] Controller 450 User's Guide
Load Calculation

Table Calculation of CPU-load from S100 and S800 Outputs

Signal type	No of signals	Basic load (ms)	Scan time (ms)	Dynamic load (ms)	Changes/sec. per signal	Total load
AO	A)	B) 0.02	C) ms E)=100*A*B/C E) %	F) 0.18	G) H)=A*G*F/10 H) %	E+H %
AOC	A)	B) 0.003	C) ms E)=100*A*B/C E) %	F) 0.03	G) H)=A*G*F/10 H) %	E+H %
DO	A)	B) 0.003	C) ms E)=100*A*B/C E) %	F) 0.13	G) H)=A*G*F/10 H) %	E+H %
DOC	A)	B) 0.003	C) ms E)=100*A*B/C E) %	F) 0.03	G) H)=A*G*F/10 H) %	E+H %
Total					 %

حساب حمل المحكمات لشبكة تحكم حاسوبية باستخدام نظرية الاحتمالات

يقدم البحث تطبيق استخدام نظرية الاحتمالات في حساب أحمال محكمات نظم التوزيع المحكمة. نظرا للتغير المستمر في حالة الوسط المطلوب التحكم فيه تستخدم نظرية الاحتمالات في حساب أحمال المحكمات المستخدمة للنظام. ونظرا لتعدد شكل المعلومات المستخدمة في عملية الحساب كالمستمرة والمتقطعة أمكن تطبيق نظرية الاحتمالات في حساب حمل المحكم. وقد أثبتت النتائج تقارب القيم المحسوبة باستخدام نظرية الاحتمالات مع القيمة المقاسة لحمل المحكم مما يبين أهمية الطريقة المقترحة لحساب حمل المحكم. وقد تم تطبيق الطريقة المقترحة على نموذج عملي وهو السد العالي ونستنتج أيضا أنه يمكن استخدام الطريقة المقترحة لحساب حمل المحكمات لأي نظام آخر.