Government of India
Central Electricity Authority
Hydro Engg. & Technology Development Division
7th Floor, Sewa Bhawan,
R.K. Puram, New Delhi – 110066

ISO:9001-2008

10/62(1)/HE&TD/2011

28th June, 2011

To all concerned

Sub: Committee Report constituted to frame guidelines for Load Acceptance Criteria for Hydro-electric Power Plants - Comments Invited from all concerned on the Report - reg.

Sir,

Secretary, CEA vide office order no. CEA/5-41(09)/Secy-2010/400 dated 30.11.2010 had constituted a committee under the Chairmanship of Chief Engineer(HE&TD), CEA with committee members drawn from CWC, NHPC, SJVNL and KPCL to frame guidelines on subject mentioned.

The committee has since submitted the report and the same has been approved by the Chairperson, CEA with the direction to make wider circulation among the various stake holders so as to invite their comments / suggestions, if any, and after taking into account the suggestions / comments, the applicable portion of the report can be implemented by proposing amendment in the relevant BIS.

With above in view, the report has been put up on CEA website http://cea.nic.in with request to all concerned including Central & State Utilities, Public & Private Developers, Consultancy Organisations, individual experts and any other civil society member to send their comments/ suggestions on the report to the undersigned in an enclosed format latest by 31st July 2011 with a copy through e-mail.

Yours faithfully,

S. Srivastava
28/6/2011

(Sanjay Srivastava)
Director & Member Secretary of the Committee
E-mail: ssrivastava@cea.nic.in

Comments / Suggestions on Committee Report on guidelines for Load Acceptance Criteria for Hydro-Electric Power Plants

Name of Organisation:

Contact Person with Designation

Communication Address

Phone / E-mail ID

S.No.	Clause / Sub-clause	Type of Comment (General / Technical / Editorial)	Comments / Suggestion	Proposed Change	Reason / Justification for Change

Report of the Committee for Framing Guidelines on Load Acceptance Criteria for Hydro-Electric Plants

A. INTRODUCTION

1. CEA vide office order no. CEA/5-41(09)/Secy-2010/400 dated 30.11.2010 (Annex-I) decided to frame specific guidelines for ramping up of load for Hydro Power Plants under various upstream hydraulic conditions, as no such guidelines/regulation exist at present. Accordingly, committee representing various organizations/utilities dealing with development of hydro power was constituted to study the issue comprehensively and frame guidelines in this regard with the following composition:-

i) Chief Engineer(HE&TD), CEA	Chairman
ii) Representative of GO&D Wing, CEA	Member
iii) Representative of CWC	Member
iv) Representative of NHPC	Member
v) Representative of SJVNL	Member
vi) Representative of KPCL	Member
vii) Director (HE&TD), CEA	Member Secretary

The committee was asked to submit its report within three months from the date of issue of order, however the same was extended up to 30.4.2011 vide office orders of even no. dated 21.2.2011 and 28.3.2011(Annex-II).

2. The Terms of Reference of the Committee is to prepare Guidelines for ramping up of load for hydro plant and standardization of load acceptance criteria as required for optimization of upstream Hydraulic Components and safe operational regime for hydro plants, under various operational constraints including sudden load throw-off followed by quick follow-on loading to full plant capacity with or without joint control mode in operation.

3. In response to CEA letter dated 30.11.10 and reminder dated 29.12.10, NHPC vide letter No. NH/DEM/3487 dated 13.12.2010, SJVNL vide letter no. SJVN/DE-04-708 dated 4.2.11, KPCL vide letter no. A1 W4FO/Gen/507 dated 6.1.2011, GO&D wing of CEA vide letter no. M(GO&D)/Misc/2010 dated 9.12.10 and CWC vide letter no. 3/4/2010-HCD(E&NE)/468 dated 24.1.2011 nominated the respective member in the said committee. Based on nomination received from the participating organizations, the Committee comprises of the following:

Sh. J.K. Khatri, C.E.(HE&TD), CEA	Chairman
Dr. R.K. Gupta, Director, HCD(E&NE), CWC	Member

Sh. Rajesh Sharma, C.E(Elect), Design(E&M), NHPC	Member
Sh. R.K. Agarwal, GM(E), SJVN Ltd.	Member
Sh. G.B. Shivamurthy, SE(EI), EI Design, KPCL	Member
Sh. Ajay Talegaonkar, SE, NRPC	Member
Sh. Sanjay Srivastava, Director(HE&TD), CEA	Member Secretary

4. After receiving nominations from the organizations the first meeting could be convened only on 28th Jan. 2011 vide CEA letter no. 10/62(1)/HE&TD/2011/86-93 dated 14th Jan. 2011. The committee members were requested to furnish Project wise details as per the format prepared by the Chairman & Member Secretary of the committee for the plants in operation under the organization of committee members and International practice for grid regulations for ramping of load for hydro plants.

B. NEED FOR LOAD ACCEPTANCE CRITERA

5. In order to determine the magnitude of surges and consequently the dimensions of the surge tank, transient analysis of the water conductor system has to be carried out. The surge tank has to be designed to accommodate the maximum and minimum water levels anticipated under worst operating conditions of the units as specified in IS-7396 (part-1).

"Maximum Upsurge Level in the surge tank shall be worked out corresponding to :

a) The full load rejection at the highest reservoir level, and

b) Where considered necessary specified load acceptance followed by full load rejection at the instant to maximum velocity in the head race tunnel and higher of the two shall be adopted.

To obtain "Minimum Downsurge Level" the worst of the following two conditions shall be considered:

a) Full load rejection at minimum reservoir level followed by specified load acceptance at the instant of maximum negative velocity in head race tunnel, and

b) Specified load acceptance at load or speed-no-load condition at the minimum reservoir level."

6. It was observed that the "Specified load acceptance" as indicated in the IS-7396(Part-I) has not been framed so far, therefore there is a need for framing load acceptance criteria for upcoming new hydro-electric projects.

C. BRIEF OF COMMITTEE MEETINGS & DELIBRATIONS

7. The first meeting of the committee was held on 28th Jan 2011 at CEA office in New Delhi, and the minutes of the meeting were circulated vide CEA letter no. 10/62(1)/HE&TD/2011/172-179 dated 2.2.2011. The outcome of the meeting is summarized hereunder:

a) Chief Engineer(HE&TD), CEA stressed the need for making specific guidelines for load acceptance for hydro units so as to optimize the surge tank design without loosing the operational flexibility of the plant.

b) Director, HCD(E&NE), CWC elaborated the operational factors on which the size of surge tank depends and informed that the surge tank could be designed for any load acceptance criteria but to optimize the civil structure a realistic load acceptance criteria needs to be specified. It was agreed that the worst case for the down surge would be when all units are running at full load and there is a temporary unloading followed by quick regaining of full load. However, after due diligence it was decided that all the possible operational sequence would be identified and transient analysis for down surge shall be carried out to single out most arduous sequence.

c) Representative of NRPC intimated that presently from off-peak to peak, there is a ramp up requirement of 200MW/min for North, East & West grid & it may further increase as the system grows. The ramp up requirement of grid is a combined requirement from all the plants. Further, with present grid loading conditions the per hertz requirement is 2000MW. However, the committee desired the ramp up pattern in such conditions. The committee members also desired the international practice of ramping up of load/load curve.

d) GM, SJVNL informed that the present practice for their Nathpa Jhakri HEP is 2MW/sec., however the same would depend on the type of turbine and rating of units. The startup time from shutdown to full load is usually 20min.

e) SE, KPCL informed that they usually start the units one by one and furnished the data desired vide CEA letter dated 14.1.2011 for 10 plants working under KPCL. He further stressed that while making the studies the length of HRT and type of turbine also needs to be considered.

f) Chief Engineer, NHPC agreed that the worst case for surge shaft design would be when machines are working in joint control mode and there is a sharp down loading

followed by quick loading. However, the committee agreed that such a case falls under rarest of rare case and there should be logic in the control system to prevent such an inadvertent operation otherwise the size of surge shaft would be unduly large.

After detailed discussions, it was concluded in the meeting that CWC would carry out the transient analysis of surge shaft for various combination of discharge & time. All members would make further efforts to find out the international practice of utilities & grid in this regard.

8. The second meeting of the committee was held on 11th March at CEA office New Delhi and the minutes of the meeting were circulated vide CEA letter no. 10/62(1)/HE&TD/2011/332-339 dated 18.3.2011. The outcome of the meeting is summarized hereunder:

a) Director, CWC informed that based on the simulation studies carried out so far, load acceptance of 1.5 to 2 MW/sec. is coming when all the units are loaded one after another. However, the ramp-up rate could be increased if sufficient gap is provided between loading of two units such that net ramp rate from 1st unit to last unit works out between 1.5 to 2 MW/sec. He further stated that the indicative rate of 1.5 to 2.0 MW is for 100-0-100 condition and in case of 0-100-100, the load acceptance could be higher because of almost stable hydraulic conditions in upstream components. The committee desired that CWC should also carry out simulations to specify the rampup rate for 0-100-100 cases as well.

b) GM, SJVNL informed that 100-0-100 case normally occurs in the event of grid fault, which is not a frequent happening (usually 2-3 cases in a year), while 0-100-100 occurs almost twice daily in peaking stations, therefore it would be appropriate to specify load acceptance for these two cases separately. He further stated that as an extra precaution, committee may consider recommending conservative approach for load acceptance for 100-0-100 cases by moderating time gap for start of first unit and loading thereafter.

c) Chief Engineer, NHPC indicated that it would be difficult for control system to differentiate load acceptance for 100-0-100 and 0-100-100 cases since units could be started either in manual mode or in auto mode from UCB/ Control room. The committee agreed this aspect need to be further deliberated with control system manufacturers to find out a possible solution.

d) SE, KPCL informed that the load acceptance criteria should consider the type of turbine in the plant as well, so that problem of cavitation is not encountered on account of committee recommendations. The committee decided that this being an E&M issue, the information in this regard shall be gathered from manufacturers. KPCL further informed that in one of their hydro plant they have considered 100-0-33 condition. However, committee felt that since these guidelines would be applicable only on new hydro plants, we may specify load acceptance criteria for 100-0-100 condition and not 100-0-50 or 100-0-75.

e) Member Secretary informed that technological progress has been made to provide infra red light based sensors in surge shaft which would monitor the water levels and in the event of down surge falling below the critical level, control action would be initiated to prevent empting of surge tank. It was agreed that this being an innovative technology, further studies should be carried out to provide a simple and reliable solution as a backup.

In the meeting, it was decided that committee shall make separate guidelines for operation condition of 100-0-100 and 0-100 based on simulation studies being done by CWC. The relevant material on action points as indicated above shall be collected & pursued by the members. Members were also encouraged to keep communicating with each other so that unanimous view could be taken on the issue.

D LOAD ACCEPTANCE FOR 100-0-100 and 0-100-100 CONDITIONS

9. After elaborate studies made on various type and sizes of hydro-electric schemes, the following load acceptance criteria has been worked out which was discussed & finalised during the third meeting of the committee held in CEA, N.Delhi on 27th April 2011.

9.1 Case 1: Load rejection by all operative machines followed by load acceptance by all machines (100-0-100)

9.1.1 **Ramping up of load for all the Units together:** When simultaneous loading of units are done through manual or joint control mode of operation from Speed No-Load condition, the ramping rate is limited to 1.5MW/sec to 2MW/sec as per graph given in fig.1 below:

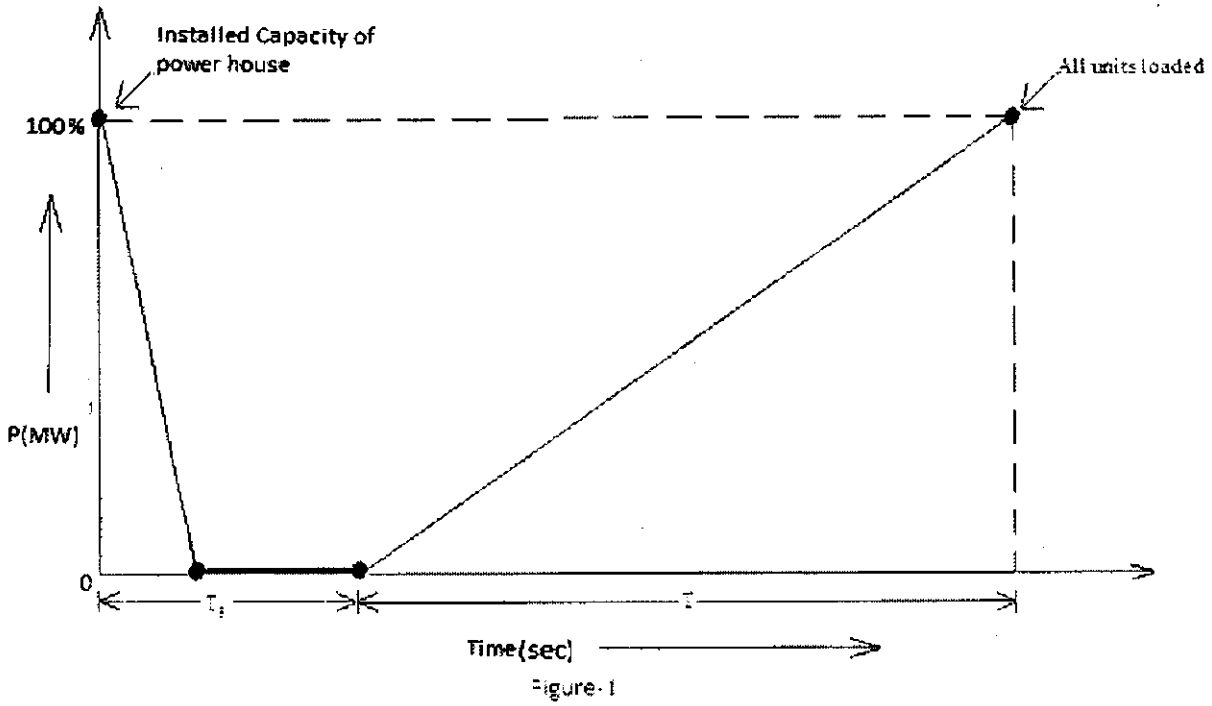

Figure-1

The total time of needle/guide vane opening from speed no-load condition to full load 'T' shall not be less than 'Ts' obtained from criteria given in para 9.1.3.

9.1.2 After detailed deliberations, it was agreed that starting of all units together shall generally be not recommended after load throw-off as the malfunctioning of hardware/software interlocks in the process may inadvertently increase the ramping-up rate of units. However, the same may adopted if proper functioning of the hardware/ software interlocks is assured by the project authorities.

9.1.3 **Ramping up of load for Units one by one:** When loading of units are done one by one through manual or auto control mode of operation from Speed No-Load condition. The ramping-up of the load shall be done as per procedure given hereunder and

shown in fig. 2 below:

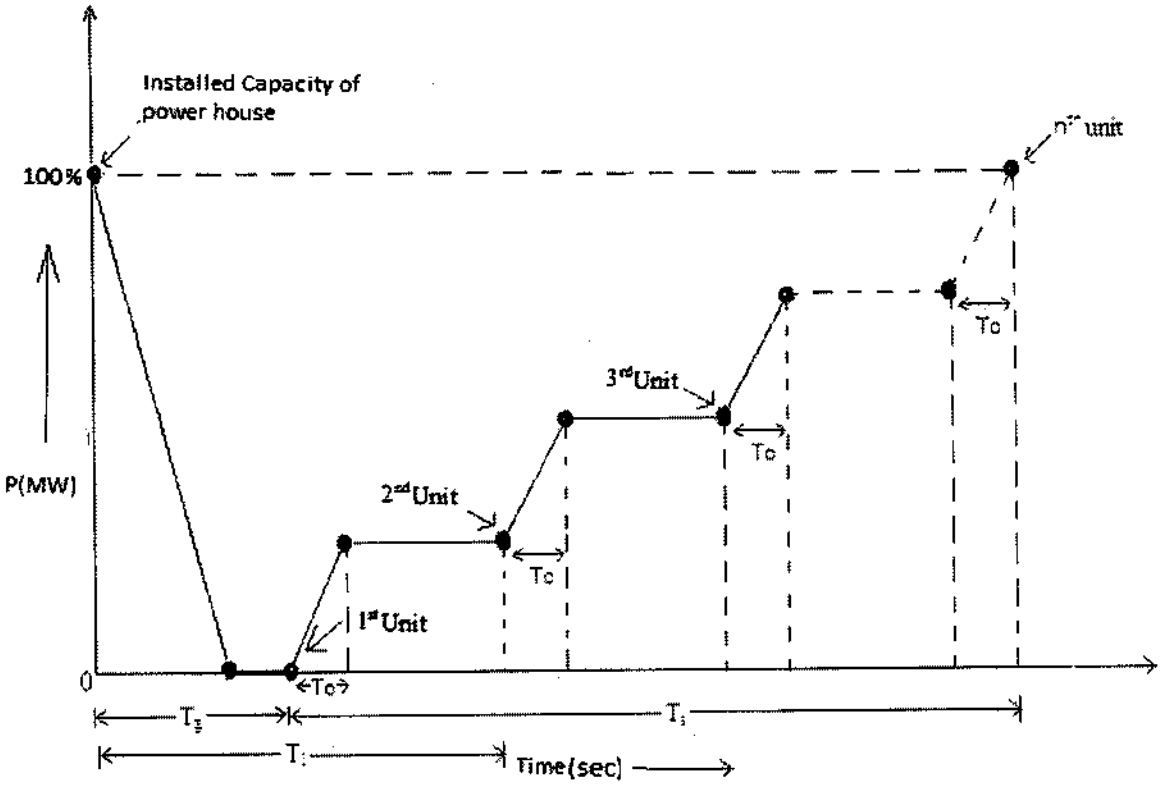

Figure-2

a) The needle/guide vane of unit shall be opened in 20-60 seconds as per manufacturer's recommendation (To)

b) The second unit shall be loaded only after time T_1 such that

$$T_1 \geq 2\pi\sqrt{(L*As/g*At)}$$

where: L is length of HRT in meters

As is area of surge tank in m^2

At is area of HRT in m^2

g is acceleration due to gravity in m/sec^2

Tg is the time in sec. from the instant of unit tripping to the start of first unit

Ts is total time of opening of all the units in sec

T_0 is the time of needle/guide vane opening of one unit in sec,

T_1 is the time in sec. from tripping of unit to opening of needle/guide vane of second unit

c) Total time of opening of needle/guide vane shall not be less than time T which is equal to installed capacity divided by the ramp rate defined for all the units are loaded together i.e 1.5MW/sec to 2MW/sec.

d) The time gap for 3rd unit till last unit shall be obtained by subtracting the time upto loading of 2nd unit from total time and dividing that by number of remaining units.

Note: i) T_1 is the time of water oscillation in the simple surge tank for frictionless system. Hence it is advisable to obtain correct value of T_1 from the surge analysis for 100-0-0 operating condition.

ii) Wherever continuous overload capacity has been specified, the maximum power output shall be considered as full load throw-off.

9.1.4 During the discussions NHPC representative desired simultaneous loading of two units for plants having 4 units or more. The issue was deliberated in detail and committee decided that simultaneous loading of two units can be considered for hydro-electric power plants having more than four units.

9.2 **Case 2: Load acceptance by all operative machines and continue to run at plant installed capacity as 0-100-100 condition**

9.2.1 **<u>Ramping up of load for all the Units together:</u>** When simultaneous loading of units are done through manual or joint control mode of operation from Speed No-Load condition the ramping rate is limited to 2.5MW/sec to 3.0MW/sec as per graph indicated below:

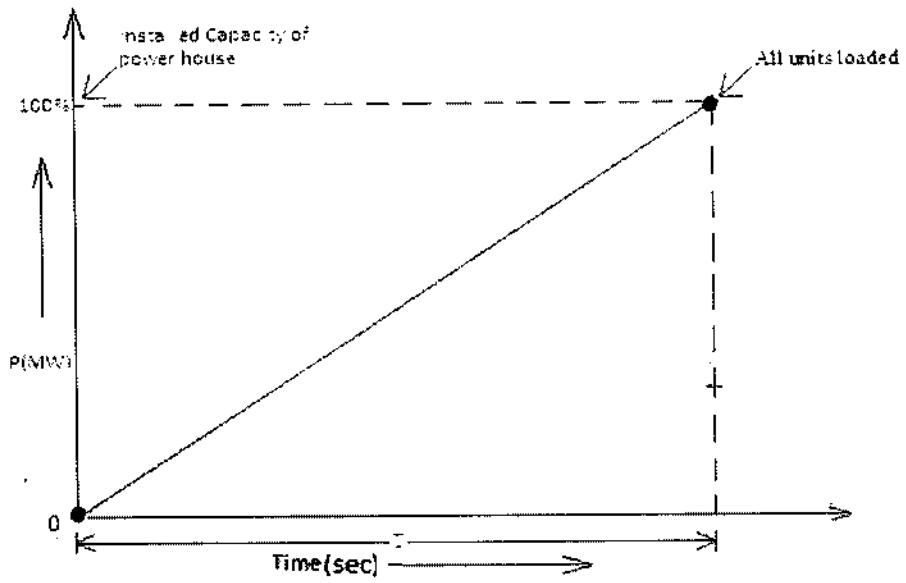

Figure-3

However, the total time of needle/guide vane opening from speed no-load condition to full load 'T' shall not be less than 'Ts' obtained from criteria given in para 9.2.3.

9.2.2 Similar to para 9.1.2, the committee decided that the starting of all units together for 0-100-100 condition shall generally be not recommended, as in this case also any malfunction of hardware/software interlock or operator mistake may inadvertently increase ramp-up rate of units. However, the same may be adopted if proper functioning of interlocks is ensured by the project authorities.

9.2.3 **Ramping up of load for Units one by one:** When loading of units are done one by one through manual or auto control mode of operation from Speed No-Load condition the ramping shall be done as per procedure given hereunder.

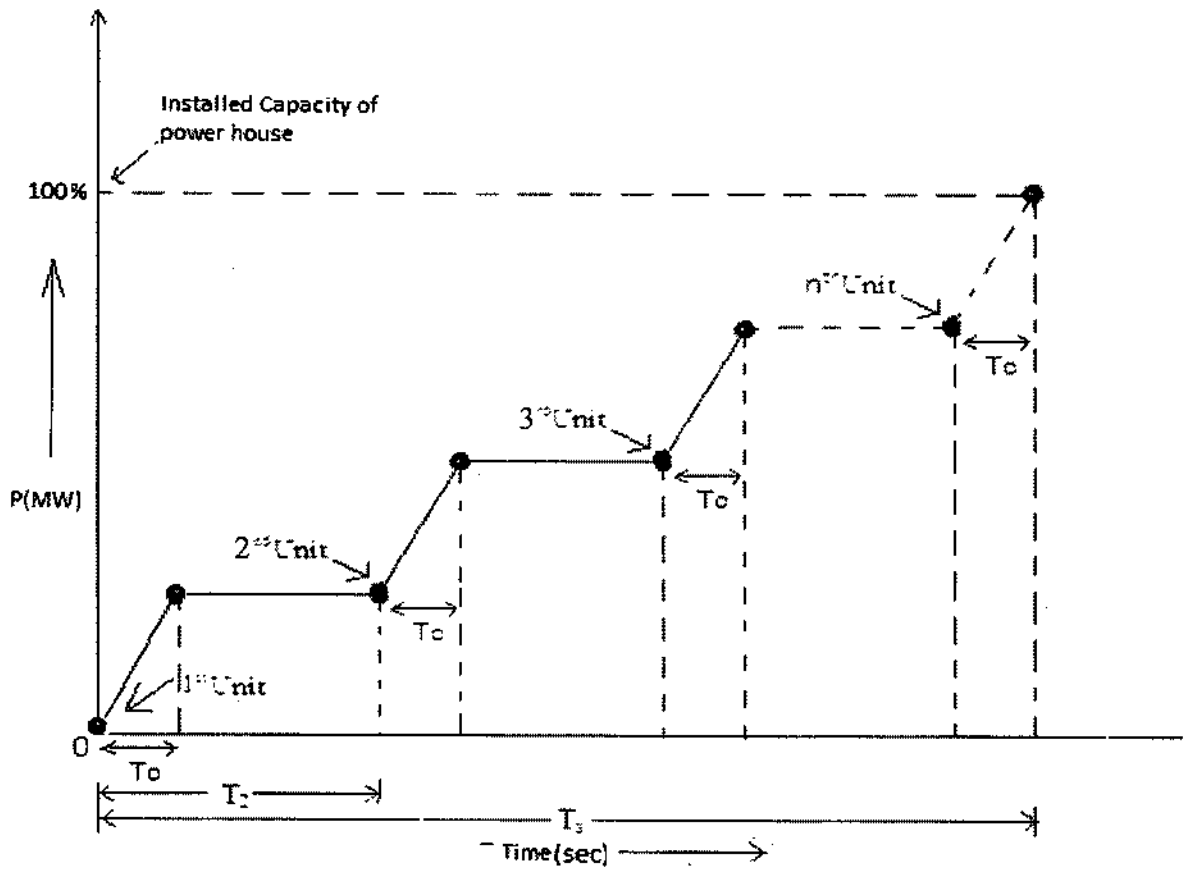

Figure- 4

a) The needle/guide vane of unit shall be opened in 20-60 seconds as per manufacturer's recommendation (To)

b) The second unit shall be loaded only after time T_2 such that

$$T_2 = \pi\sqrt{(L*As/g*A_t)}$$

where: L is length of HRT in meters

As is area of surge tank in m^2

At is area of HRT in m^2

g is acceleration due to gravity in m/sec^2

Ts is total time of opening of all the units in sec

T_0 is the time of needle/guide vane opening of one unit in sec,

T_2 is the time of start of needle/guide vane opening of second unit from beginning in sec.

c) Total time of opening of needle/guide vane 'Ts' shall not be less than time 'T' which is equal to installed capacity divided by the ramp rate defined for all the units are loaded together i.e 2.5MW/sec to 3MW/sec.

e) The time gap for 3rd unit till last unit shall be obtained by subtracting the time up to loading of 2nd unit from total time and dividing that by number of remaining units.

Note: T_2 is the time of half oscillation in the simple surge shaft for frictionless system. Hence, it is advisable to obtain correct value of T_2 from the surge analysis for 0 - 1 unit – 1 unit operating condition.

9.2.4 Similar to para 9.1.4, simultaneous loading of two units can be considered for hydro-electric power plants having more than four units.

10. To further clarify the above stipulations a typical illustration has been made at Annex-III.

11. The above guidelines are applicable for all hydro schemes having HRT & surge shaft. However, the committee felt that for Dam toe projects there would be no restriction on load acceptance criteria and the loading guidelines as recommended by the manufacturer, shall be applicable.

12. The committee made all out effort to find the international practice followed by the utilities and the grid regulators world wide, however no such data is available in public domain. Therefore these guidelines could not be checked with the international practice.

E Applicability of these Load Acceptance Criteria

13. The committee decided that the applicability of these load acceptance criteria shall be made only to new hydro-electric scheme being planned considering these guidelines. However, the plants already built shall continue to operate as per operational guidelines approved by the respective utility.

F Recommendations

14. Based on the information available with the committee and the studies made, the load acceptance criteria as indicated in para D9.1 & D9.2 for 100-0-100 and 0-100-100 conditions respectively may be adopted for new hydroelectric plants.

15. Necessary provisions shall be made in unit and plant control system which could detect the initial condition from which the plant shall be started so that the rampup constraints could be effectively followed.

16. Infra red light based sensors in surge shaft may be used, wherever feasible so that water level in the surge shaft could be monitored and in the event of water level falling below the critical level during down surge, control action would be initiated to stop the units.

(R.K. Gupta)
Director, HCD (E&NE),
CWC

(Rajesh Sharma)
Chief Engineer, Design(E&M)
NHPC

27/4/11
(R.K. Agarwal)
General Manager (Elect.)
SJVN Ltd

(G.B. Shivamurthy)
Superintending Engineer(EI)
KPCL

27.04.2011
(Ajay Talegaonkar)
Superintending Engineer,
NRPC

27/4/2011
(Sanjay Srivastava)
Director(HE&TD), CEA
Member Secretary

(J.K. Khatri)
Chief Engineer(HE&TD), CEA
Chairman of the Committee

Annex - I

भारत सरकार
केन्द्रीय विद्युत प्राधिकरण
सचिव का कार्यालय
सेवा भवन, आर0 के0 पुरम्,
नई दिल्ली - 110 066
****

No.CEA/5-41(09)/Secy-2010/400 Dated: 30.11.2010

ORDER

Subject: Constitution of Committee to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants – reg.

It has been decided to frame specific guidelines for ramping up of load for Hydro Power Plants under various upstream hydraulic conditions, as no such guidelines/regulation exist at present. Accordingly, a Committee representing various organizations/ utilities dealing with development of hydro power is hereby constituted to study the issue comprehensively and frame guidelines in this regard with the following composition:-

1. Chief Engineer (HE&TD), CEA	Chairman
2. Representative of GO&D Wing, CEA	Member
3. Representative of CWC	Member
4. Representative of NHPC	Member
5. Representative of SJVNL	Member
6. Representative of KPCL	Member
7. Director, (HE&TD-III), CEA	Member Secretary

The Terms of Reference of the Committee would be to prepare Guidelines for ramping up of load for hydro plant and standardization of load acceptance criteria as required for optimization of upstream Hydraulic Components and safe operational regime for hydro plants, under various operational constraints including sudden load throw-off followed by quick follow-on loading to full plant capacity with or without joint control mode in operation.

The Committee shall submit its Report within three months from the date of issue of this Order.

This issues with the approval of Chairperson, CEA.

(Amarjeet Singh)
Secretary.

To:

1. Shri J.K. Khatri, Chief Engineer(HE&TD), CEA.
2. Shri Sanjay Srivastava, Director, (HE&TD-III), CEA

Copy, with the request to kindly confirm nomination of a senior level officer from your organization so as to entail wider acceptability of the Guidelines framed by the Committee by Fax to Shri J.K. Khatri, Chief Engineer(HE&TD) at Telefax No.011-26107132, to:

1. Chairman, CWC, Sewa Bhawan, R.K. Puram, New Delhi
2. Member (Grid Operation), CEA, Sewa Bhawan, R.K. Puram, New Delhi
3. Shri S.K. Garg, Chairman & Managing Director, National Hydroelectric Power Corporation, NHPC Office Complex, Sector-33, Faridabad-121003 [Tel: 0129-2275920, Fax: 0129-2278020]
4. Shri H.K. Sharma, Chairman & Managing Director, Satluj Jal Vidyut Nigam Ltd., Himfed Building, New Shimla, Shimla-171009 [Tel: 0177-2670804, Fax: 0177-2670893]
5. Shri S.M. Jaamdar, Managing Director, Karnataka Power Corporation Ltd., Shakthi Bhawan, No.82, Race Course Road, Bangalore-560001 [Tel: 080-22214342, Fax: 080-22213526]

Copy for information to :

1. SA to Chairperson, CEA
2. SA to Member (Hydro), CEA

(Amarjeet Singh)
Secretary

Annex- II A

भारत सरकार
केन्द्रीय विद्युत प्राधिकरण
सचिव का कार्यालय
सेवा भवन, आर0 के0 पुरम,
नई दिल्ली - 110 066
****

No.CEA/5-41(09)/Secy-2010/ 813

Dated: 21.02.2011

ORDER

Subject: Constitution of Committee to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants – reg.

A Committee was constituted vide Office Order of even No. dated 30.11.2010 to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants indicating therein that the Committee shall submit its report within three months from the date of issue of this Office Order. Chairman of the Committee has now requested for grant of extension for submission of report by the Committee.

Accordingly, an extension of one month i.e. upto **31st March, 2011** is hereby granted for submission of report by the Committee. All other terms & conditions of the Committee will remain the same.

This issues with the approval of Chairperson, CEA.

(Amarjeet Singh)
Secretary

To:

1. Shri J.K. Khan, Chief Engineer(HE&TD) & Chairman of the Committee.
2. Shri Sanjay Srivastava, Director, (HE&TD-III) & Member Secretary of the Committee.

Copy for information to :

1. SA to Chairperson, CEA
2. SA to Member (Hydro), CEA

Amen-II B

भारत सरकार
केन्द्रीय विद्युत प्राधिकरण
सचिव का कार्यालय
सेवा भवन, आर0 के0 पुरम्,
नई दिल्ली - 110 066
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(आई.एस.ओ.: 9001:2000)

No.CEA/5-41(09)/Secy-2010/84

Dated: 28.03.2011

ORDER

Subject: Constitution of Committee to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants – reg.

A Committee was constituted vide Office Order of even No. dated 30.11.2010 to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants indicating therein that the Committee shall submit its report within three months from the date of issue of this Office Order i.e. upto 28th February, 2011. An extension of one month i.e. upto 31st March, 2011 was granted vide Order of even No. dated 21.02.2011for submission of report by the Committee. Now, the Chairman of the Committee has requested for grant of further extension of one month i.e. upto **30th April, 2011** for submission of report by the Committee.

Accordingly, Chairperson, CEA has approved the extension of one month i.e. upto **30th April, 2011** for submission of report by the Committee to frame Guidelines for Load Acceptance Criteria for Hydro-electric Power Plants. All other terms & conditions of the Committee will remain the same.

(Amarjeet Singh) 28/3/11
Secretary

To:

1. Shri J.K. Khatri, Chief Engineer (HE&TD) & Chairman of the Committee.
2. Shri Sanjay Srivastava, Director, (HE&TD-III) & Member Secretary of the Committee.

Copy for information to : file No 10/62(1)/HE&TD/2011 along with

1. SA to Chairperson, CEA
2. SA to Member (Hydro), CEA

Annex-III

Typical Illustration for 100-0-100 and 0-100-100 Condition

Assuming basic parameters of a hydro-electric plant as under:

Installed Capacity	=	6 x 200 MW
Length of HRT	=	9000 m
Area of HRT	=	78.5 m^2
Area of Surge Shaft	=	471.4 m^2

i) 100-0-100 Operating Condition:

a) Ramping up all units together at the rate of 2 MW/sec. (say)

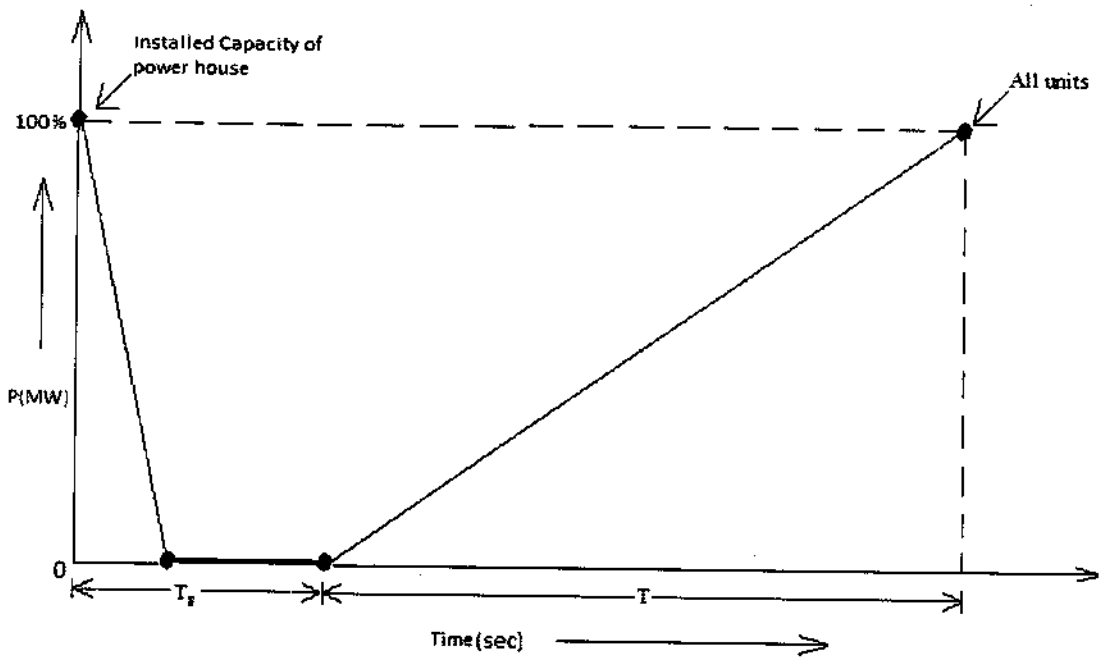

Figure-1

$T = 1200/2 = 600$ sec.

b) Loading of units one by one

$T = 2\pi\sqrt{(L*As/g*At)}$

$= 466$ sec.

The second unit shall start after 466 sec from the instance tripping occurs.

Let us assume that first unit starts after 220 seconds from the instance tripping occurs. In this case, load acceptance curve becomes as given in the following figure.

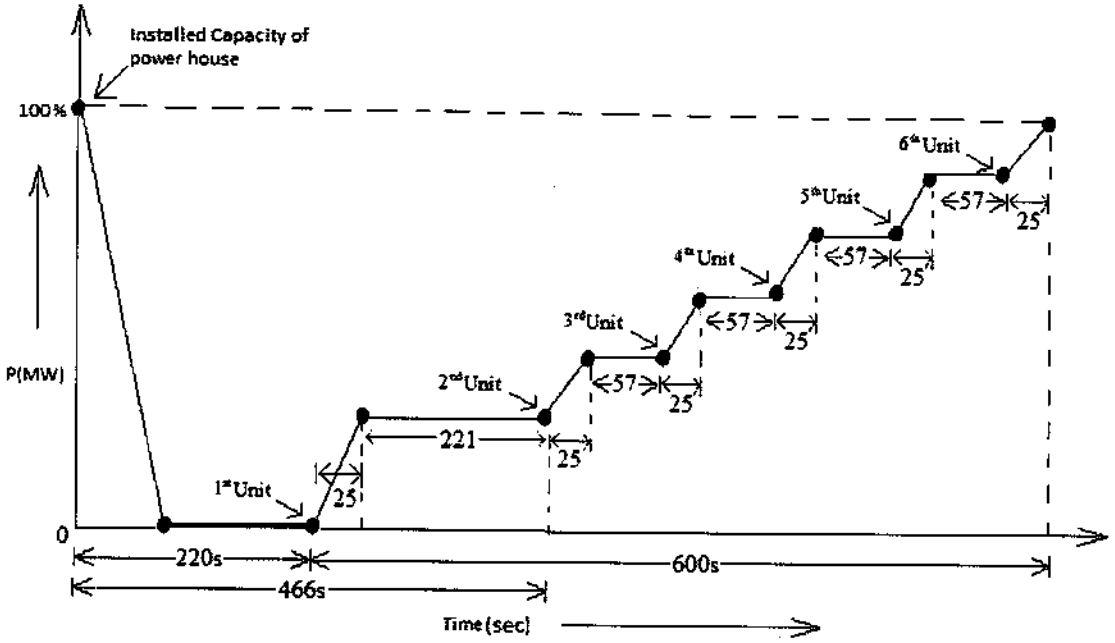

Figure-2

Total time of opening of all units = 600 sec.
Time of opening of guide vanes of one unit = 25 sec. (say)
Time gap between start of second unit after opening of first unit = 466-220-25=221 sec.
Time gap between start of other units after opening of previous unit = [600-221-(25x6)]/4=57 sec. (approx.)

ii) 0-100-100 Operating Condition

a) Ramping up all units together at the rate of 2.5 MW/sec. (say)

$T=1200/2.5 = 480$ sec.

b) Loading of units one by one

$T_l=233$ sec.

Second unit shall start after 233 seconds from the instance first unit starts.
Total time of opening of all units = 480 sec.

Time of opening of guide vanes of one unit = 25 sec (say)
Time gap between start of second unit after opening of first unit = 233 – 25 = 208 sec.

Time gap between start of other units after opening of previous unit

= [480 – 208 – (25 x 6)]/4

= 30 sec

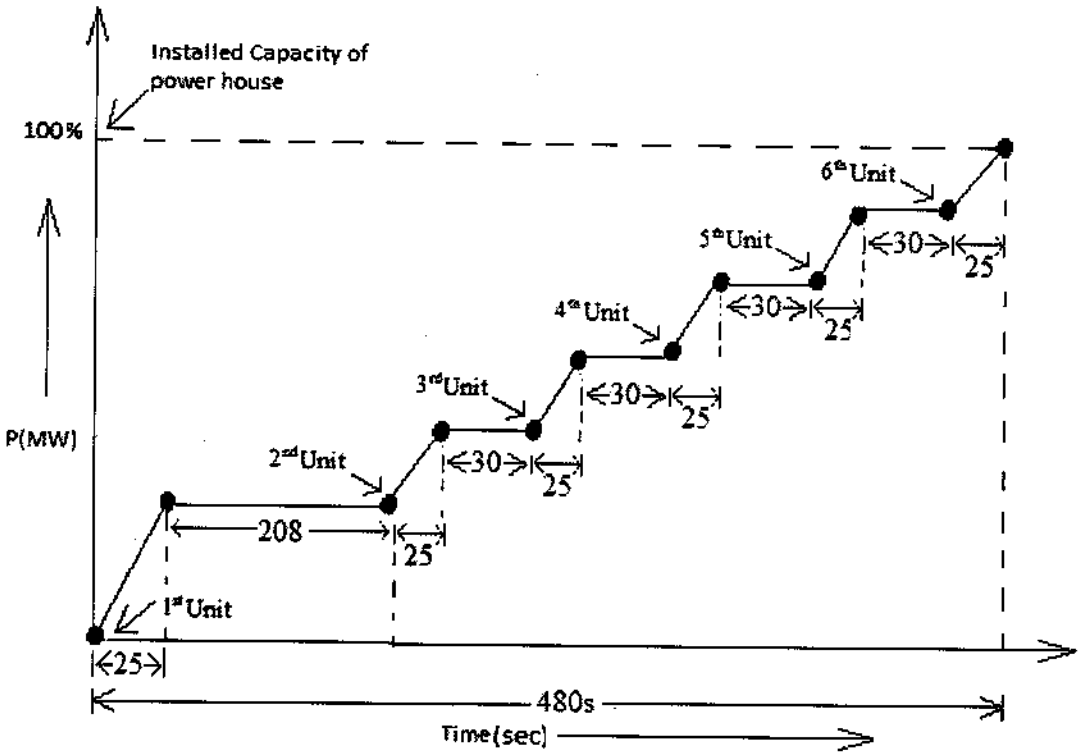

Figure-3