G.H. Mittendorf Jr.

PUB. NO. HT 4-1958
SEPTEMBER 1958

NEMA
REG. U.S. PAT. OFF.

Determination of WR^2 for

HYDRAULIC TURBINE GENERATOR UNITS

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION
155 EAST 44th STREET NEW YORK 17, N. Y.

NEMA STANDARDIZATION

The purpose of NEMA Standards, their classification and status are set forth in certain clauses of the NEMA By-Laws, which are quoted below:

Purpose of Standards

National Electrical Manufacturers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining the proper product for its particular need. Existence of a National Electrical Manufacturers Association Standard does not in any respect preclude any member or non-member from manufacturing or selling products not conforming to the Standard.

(By-Law--Art. V, Sec. 1)

Definition of a Standard

A Standard of the National Electrical Manufacturers Association defines a product, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and the service for which designed.

(By-Law--Art. V, Sec. 2, Subsection A)

Classes of Standards

National Electrical Manufacturers Association Standards are of two classes:

1. NEMA Standard, which relates to a product commercially standardized and subject to repetitive manufacture, which standard has been approved by at least 90 per cent of the members of the Subdivision eligible to vote thereon;

2. Suggested Standard for Future Design, which may not have been regularly applied to a commercial product, but which suggests a sound engineering approach to future development, which standard has been approved by at least two-thirds of the members of the Subdivision eligible to vote thereon.

(By-Law--Art. V, Sec. 2, Subsection B)

Authorized Engineering Information

Authorized Engineering Information consists of explanatory data and other engineering information of an informative character not falling within the classification of NEMA Standard or Suggested Standard for Future Design.

(By-Law--Art. V, Sec. 6, 1st sentence)

Identification of Status

At the end of each standard in this publication appear the words "NEMA Standard" or "Suggested Standard for Future Design," which indicate the status of the standard. These words are followed by a date which indicates when that standard was adopted in its present form by the Association.

The classification "Authorized Engineering Information" is designated similarly.

* * *

DETERMINATION OF WR^2 FOR HYDRAULIC TURBINE GENERATOR UNITS

HT 4-1.01 Description of Terms

C — Unit regulating constant: $\frac{WR^2(rpm_o)^2}{hp_o}$

C_T — Combined regulating constant of the connected units on the smallest portion of the system that the unit will be required to regulate, exclusive of the regulating constant of the unit under consideration.

$\frac{\Sigma(LV_o)}{H_o}$ — Pipe line factor:

$$\frac{LV_o \text{ (penstock)} + LV_o \text{ (draft tube)} + 0.5\, LV_o \text{ (casing)}}{H_o}$$

$\Sigma(LV_o) \geqq \frac{5.3\ A}{H_o}$ for open flume setting

$\Sigma(LV_o) \geqq \frac{8\ A}{H_o}$ for enclosed casing

A — Runner outlet diameter in inches.

H_o — Design head corresponding to $\Sigma(L)$ in feet.

hp_o — Design capacity in horsepower of the hydraulic turbine.

L — Length in feet of various water passages of the turbine and penstock from intake (or surge tank normal water level) to draft tube exit.

mw_o — Design capacity in megawatts of the turbine generator unit (assumed to be 20 for units of 20 mw or less and 50 for units of 50 mw or more).

rpm_o — Normal speed of the unit in revolutions per minute.

V_o — Average design water velocity in feet per second corresponding to L.

WR^2 — Total flywheel effect of the turbine generator unit in pounds-feet^2.

Authorized Engineering Information 7-16-1958.

HT 4-1.02 Minimum Conditions

If the pipe line constant $\left(\frac{\Sigma LV_o}{H_o}\right)$ is less than 80, for acceptable operation under normal operation, the regulating constant (C) of a hydraulic turbine generator unit should be not less than:

(I) $\frac{5,000,000}{mw_o} \quad \frac{\Sigma (LV_o)}{H_o}$ for an isolated unit

(II) $\frac{5,000,000}{mw_o} \quad \frac{\Sigma (LV_o)}{H_o} - C_T$ for a unit operating interconnected with other generating units

(III) $100,000 \quad \frac{\Sigma (LV_o)}{H_o}$ minimum for satisfactory synchronizing of unit

(IV) 4,000,000

If the pipe line factor $\left(\frac{\Sigma LV_o}{H_o}\right)$ exceeds 80, consideration should be given to reducing the water hammer effect (as it influences speed regulation) by the installation of a surge tank or pressure regulator.

Authorized Engineering Information 7-16-1958.

HT 4-1.03 Basic Assumptions

The conditions given in HT 4-1.02 are based on the following assumptions:

A. With Regard to the Normal Operation of the Interconnected Network

1. A system frequency of 60 cycles per second.
2. Maximum frequency variation of 1 1/2 cycles per second per megawatt load change on the system for units exceeding 20 mw_o capacity or 1 1/2 cps per 5 per cent load change for units smaller than 20 mw_o capacity.
3. Purely resistive load. The self-regulating effect of a specific system will modify assumption A.2.
4. System recovery time after a step load change of not over 20 seconds. If the load changes are gradual, the recovery time may be lengthened.
5. In the case of an interconnected system (condition II), the unit under consideration regulates the system with other interconnected units blocked.
6. The design of the electrical network is such that, with the required adjustments of the governing system, magnification of frequency oscillation will not occur.
7. Substantially constant system voltage.

B. With Regard to the Hydraulic Turbine Generator Unit

1. A synchronous generator directly connected to a Francis or a fixed or adjustable propeller-type turbine.
2. The generator, turbine, governor and voltage regulator are presumed to be inherently stable and capable of stable operation under design conditions.
3. A surge tank, when used, inherently stable on small load changes.

4. No relief valve.
5. A control system without dead band.
6. Straight line relationship between gate motion and power output and linear action during transients. This is valid for small deviations such that the boundary limits, i.e., stops on servomotors, valves, speed sensing elements or by-pass of compensating device, are not reached.

Authorized Engineering Information 7-16-1958.

HT 4-1.04 Description of Chart

The accompanying chart facilitates the determination of the required regulating constant in accordance with the conditions given in HT 4-1.02.

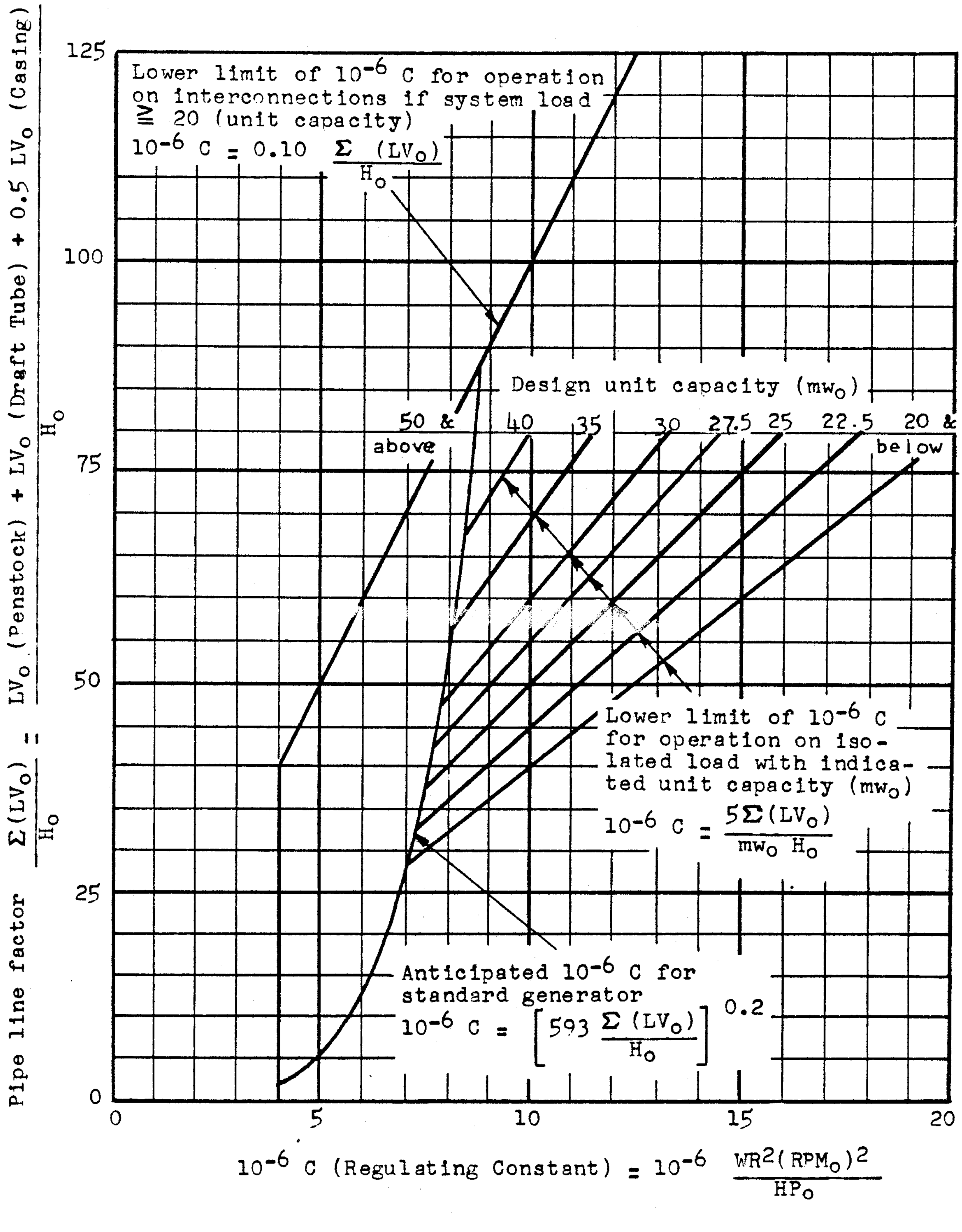
For operation on a large system, the unit regulating constant (C) should fall above the lower line on the chart; therefore, C = 4,000,000 for $\frac{\Sigma(LV_o)}{H} \leqq 40$ and $C = 0.10 \frac{\Sigma(LV_o)}{H_o}$ millions when $\frac{\Sigma(LV_o)}{H_o} \geqq 40$.

For operation as an isolated unit, the unit regulating constant is determined by the family of lines designated 20 mw_o and below to 50 mw_o and above for $\frac{\Sigma(LV_o)}{H_o} \geqq 28$. For $\frac{\Sigma(LV_o)}{H_c} \leqq 28$, it is determined by the line

$C = \left[593 \frac{\Sigma(LV_o)}{H_o}\right]^{0.2}$ millions. For convenience in preliminary estimates, the line $C = \left[593 \frac{\Sigma(LV_c)}{H_o}\right]^{0.2}$ millions has been extended from 20 mw_o to 5 mw_o to indicate the anticipated C for standard generators of the indicated mw_o capacity. Thus, for example, a 25 mw_o unit with $\frac{\Sigma(LV_o)}{H_o} = 25$ would have sufficient WR^2 for isolated operation. The anticipated regulating constant inherent in a standard 25 mw_o generator is 7.4 millions. The required unit regulating constant is 6.8 millions. If, on the othher hand, the $\frac{\Sigma(LV_o)}{H_o}$ were 50, then the unit regulating constant required for isolated operation would be 10 millions and 2.6 million regulating constant should be supplied by the rotating parts of the turbine and extra WR^2.

The operation of a proposed installation should be checked for the <u>smallest</u> connected network the unit will be required to regulate if separated from a normally larger interconnection. Under such circumstances, the normal frequency swings should be held to magnitudes such that the two systems can be resynchronized without difficulty.

Authorized Engineering Information 7-16-1958.



Lower limit of 10^{-6} C for operation on interconnections if system load ≧ 20 (unit capacity)
$10^{-6}\ C = 0.10\ \frac{\Sigma (LV_o)}{H_o}$
Design unit capacity (mw_o)
50 & above
40
35
30
27.5
25
22.5
20 & below
Lower limit of 10^{-6} C for operation on isolated load with indicated unit capacity (mw_o)
$10^{-6}\ C = \frac{5\Sigma (LV_o)}{mw_o\ H_o}$
Anticipated 10^{-6} C for standard generator
$10^{-6}\ C = \left[593\ \frac{\Sigma (LV_o)}{H_o}\right]^{0.2}$
Pipe line factor $\frac{\Sigma (LV_o)}{H_o} = \frac{LV_o \text{ (Penstock)} + LV_o \text{ (Draft Tube)} + 0.5\ LV_o \text{ (Casing)}}{H_o}$
10^{-6} C (Regulating Constant) $= 10^{-6}\ \frac{WR^2 (RPM_o)^2}{HP_o}$
0
5
10
15
20
25
50
75
100
125