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An Empirical Formula for Determining Powerhouse Size

By J. L. Gordon

Powerhouse size in some projects is dictated by the size of the generator casing. Designers usually have to rely on equipment manufacturers to provide this information. Now there is an empirical formula to determine generator casing diameter.

For medium to high head projects, the size of the powerhouse envelope is usually governed by the diameter of the generator casing. Now, based on an analysis of 120 generators, an empirical formula for generator casing diameter is available for use during initial conceptual design.

Before the layout of a hydroelectric powerhouse can be determined, the designer must know the size of the equipment. Several formulae can be used to determine the size of the turbine unit and, therefore, the powerhouse substructure.[1,2,3]

However, with no formula available to determine the size of the generating equipment, the designer must rely on equipment manufacturers to provide the required information.

When head is less than 100 m (about 330 feet), the size of the powerhouse and its concrete volume are typically a function of the turbine size. But when head exceeds 100 m, the size of the generator usually governs unit spacing and powerhouse concrete volume. This is because the size of the generator relative to the turbine increases as the head increases.[4]

Therefore, the size of the generator eventually determines powerhouse dimensions in medium- to high-head projects.

Studies of high-head powerplants have shown that no method was readily available to determine the physical size of the generator and the adequacy of the plant's estimated size. To remedy this situation, we conducted an analysis of approximately 120 generators to develop an empirical formula for the generator casing—or housing—diameter.

Formula Development

The size of a generator casing is primarily determined by four parameters: speed of rotation, rating in kVA, rotor inertia, and voltage. Generator data from our files and data provided by the Corps of Engineers[5] were combined to obtain these parameters.

After the data was collected (see Table 1) a review indicated that the voltage parameter should be discarded, since most generators produce power at 13.8 kV, and insufficient data was available on other voltages. (However, higher generator voltages tend to reduce generator casing diameter since the generator requires less copper.)

During the analysis, an empirical expression for the casing diameter could not be developed to include the inertia expressed as a function of the generator rating and speed. Therefore, the inertia figure was converted to a factor based on a multiple of unity; "standard inertia" was given a value of 1.0 and defined by J.

Standard inertia was given the value of:

$$GD^2_s = 310{,}000\ MVA^{1.25} n^{-1.875} \qquad (1)$$

Where GD^2_s = Standard inertia in tonne-meters squared.

MVA = Generator rating in megavolt-amperes.

n = Speed in revolutions per minute

Note that inertia is expressed as a function of rotating weight times rotational diameter of the center of mass squared. Where inertia is expressed in foot-pound units as WR^2, the rotating weight (W) is expressed in pounds and the rotational radius (R) is used.

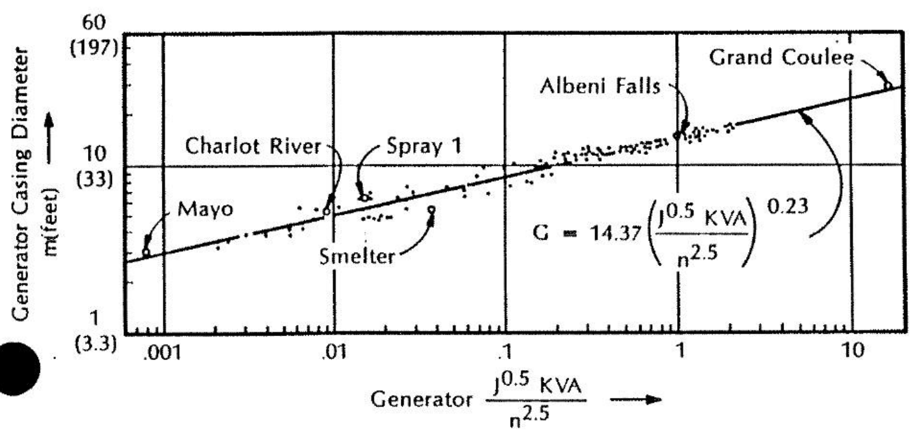

Figure 1: Generator Casing Diameter Relation

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Power Plant	Generator Rating KVA	Generator Speed rpm	Inertia Ratio J	Casing Diameter Gm	Power Plant	Generator Rating KVA	Generator Speed rpm	Inertia Ratio J	Casing Diameter Gm
Grand Coulee	615,385	72	1.37	25.56	Laurel 1	67,778	144	1.34	12.09
[illegible]em	320,000	166.7	1.56	14.45	Chief Joseph 1-5, 14-16	67,368	100	1.33	12.95
[illegible]orshak 3	231,579	128.6	1.09	14.68	Big Bend 1-8	61,579	81.8	1.33	13.92
La Grande 3 1-12	212,000	112.5	1.00	15.85	Bonneville 3-10	60,000	75	1.21	14.63
Bay D'Espoir 7	172,000	225	1.30	10.67	Beaver 1-2	58,947	105.9	1.20	12.50
Big Bend 2	170,000	150	1.12	11.68	Bighorn	57,000	180	1.77	10.06
New Melones 1-2	166,667	171.4	1.23	12.80	Detroit 1-2	55,555.	163.6	1.48	11.68
Big Bend 1	160,000	163.6	1.33	11.68	Table Rock 1-4	52,632	128.6	1.39	11.58
Little Goose 1-6	142,105	90	1.24	16.46	Broken Bow 1-2	52,632	128.6	1.19	12.19
John Day 1-16	142,105	90	1.24	16.46	Greens Ferry	50,326	120	1.29	11.58
Carters 1-2	131,579	163.6	1.68	12.80	Wolf Creek 1-6	50,000	105.9	1.41	12.19
Kainji 5 & 6	126,000	107.2	1.28	14.40	Center Hill 1-3	50,000	105.9	1.41	12.19
Ice Harbor 4-6	116,800	85.7	1.22	16.46	Bonneville 1-2	48,000	75	1.60	14.63
Libby 1-4	110,526	128.6	1.34	12.50	Stockton 1	47,579	75	1.24	14.63
Libby 5-8	110,526	128.6	1.16	13.23	Spray 1	47,500	450	1.86	6.40
Jebba 1-6	103,500	93.75	1.28	14.78	Spray 2	47,500	450	1.78	6.40
Chief Joseph 17-27	100,000	112.5	1.17	14.02	Bull Shoals 5-8	47,368	128.6	1.34	12.19
Ice Harbor 1-3	94,737	90	1.33	14.94	Lookout Point 1-3	47,222	128.6	1.05	11.28
Dworshak 1-2	94,737	200	1.38	11.00	Clark Hill 1-7	44,444	100	1.47	12.50
The Dalles 15-22	90,500	80	1.18	15.34	Buford 1-2	44,444	100	2.14	13.21
Oahe 1-7	89,474	100	1.84	14.94	Green Peter 1-2	42,105	163.6	1.58	9.81
Garrison 1-3	84,210	90	1.48	15.39	Fort Randall 1-8	42,105	85.7	1.75	13.11
Garrison 4-5	84,210	90	1.24	15.39	Fort Peck (2nd) 4-5	42,105	128.6	1.81	10.77
Bayano 1-2	84,000	120	1.21	13.00	Degray 1	42,105	150	2.08	11.89
The Dalles 1-14	82,105	85.7	1.28	15.44	Bull Shoals 1-4	42,100	128.6	1.56	12.19
NcNary 1-12	73,684	85.7	1.38	15.75	Blakely Mtn. 1-2	41,667	120	1.79	12.19
McNary 13-14	73,684	85.7	1.79	15.75	Allatoona 1-2	40,000	112.5	1.48	11.58
Hartwell 1-4	73,333	100	1.37	13.41	Smelter	40,000	257	0.98	5.49
Bonneville 2 11-18	70,000	69.2	1.25	15.85	Norfolk 1-2	38,889	128.6	1.52	11.07
Chute Willson	70,000	180	1.37	8.79	Fort Peck (1st) 1	38,889	128.6	1.52	10.97

[illegible]able 1: Generator Data
[illegible]bulated By Descending Unit Size)

The conversion factor between the English-unit and metric-unit expressions is:

$$WR^2\text{(in foot-pounds)} = 5{,}932\ GD^2\text{(in tonne-meters)} \quad (2)$$

The inertia ratio was then expressed as a function J where:

$$J = GD^2/GD^2_s \quad (3)$$

For the generators included in this analysis, it was found that the inertia ratio varied from a low of 0.975 to a maximum of 2.85.

Numerous formulae were tried; the best fit was found with the following expression.

$$G = 14.37\, J^{0.115} kVA^{0.23} n^{-0.575} \quad (4)$$

Where G = Generator casing diameter in meters

[illegible]A = Generator rating in kilovolt amperes

The data is plotted in Figure 1, on which six units are identified as having the maximum or minimum of the parameters as follows:

Generator	Parameter
Grand Coulee	Max. kVA
Mayo	Min. kVA
Spray 1	Max. rpm
Albeni Falls	Min. rpm
Charlot River	Max. J
Smelter	Min. J

Conclusions

From Figure 1, note that the generator casing diameter can vary from that predicted by Formula (4) by up to ± 1.2 m (about 4 feet), no doubt because of generator designers' latitude in determining rotor diameter. Therefore, use of the formula should be confined to preliminary studies. For feasibility studies, several manufacturers should be requested to submit estimates of equipment size.

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Power Plant	Generator Rating KVA	Generator Speed rpm	Inertia Ratio J	Casing Diameter Gm	Power Plant	Generator Rating KVA	Generator Speed rpm	Inertia Ratio J	Casing Diameter Gm
Dardanelle 1-4	37,632	75	1.04	13.01	Albeni Falls 1-3	15,778	54.4	1.71	14.78
Cordell Hull 1-3	37,037	65.5	1.73	16.51	Dexter 1-2	15,000	128.6	1.50	9.65
West Point 2-3	36,842	100	1.19	12.40	Pocaterra	15,000	240	1.34	4.93
Keystone 1-2	36,842	120	1.43	11.63	The Dalles F1, F2	14,210	200	1.18	7.49
Denison 1-2	36,842	90	1.52	11.94	John H. Kerr 1	13,333	138.5	1.66	9.65
Walter F. George 1-4	36,111	112.5	1.73	10.97	Cheatham 1-3	13,333	60	2.19	13.46
Barkley 1-4	36,111	65.5	1.78	15.24	Fort Gibson 1-4	12,500	100	1.76	8.53
John H. Kerr 2-7	35,555	85.7	1.59	12.95	Menihek 3	12,000	150	1.76	6.48
Gavins Point 1-3	35,100	75	1.68	14.58	Waterloo Lake	11,250	225	1.56	4.78
Rundle (New)	35,000	300	1.37	5.49	Kananaskis 3	11,250	225	1.43	4.78
Eufaula 1-3	31,579	100	1.31	11.94	Jim Woodruff 1-3	11,111	75	1.76	11.53
Old Hickory 1-4	31,250	75	1.69	13.92	Narrows 1-2	9,444	225	1.69	6.71
J. Percy Priest 1	31,111	128.6	1.87	11.73	Narrows 5	9,444	225	1.69	6.40
Jim Gray	30,000	277	1.59	6.91	White Horse 3	9,400	200	2.05	6.40
Robert S. Kerr 1-4	28,947	75	1.64	13.62	Horsechops	9,000	450	1.32	3.56
Clarence Cannon 1	28,421	128.6	1.16	10.67	Philpott 1-2	7,500	277	1.67	4.85
Sam Rayburn 1-2	27,368	120	1.43	9.96	Brochet	7,500	180	1.64	4.98
Millers Ferry 1-3	26,316	69.3	1.38	13.26	Sandy Brook	7,000	300	2.18	4.19
Kundah 1	24,000	428.5	1.55	5.54	Snare 1	7,000	123.5	2.00	7.16
Ghost 4	23,500	150	1.61	7.57	Snare 2	7,000	225	1.42	5.64
Cascade 2	20,000	300	1.54	4.78	Cape Broyle	7,000	360	1.19	3.86
Rundle 1	20,000	300	1.38	4.78	White Horse 1-2	6,700	300	1.66	4.20
Dale Hollow 1-3	20,000	163.6	1.37	8.64	Buford 3	6,667	277	1.45	5.59
Hart Jaune	19,000	200	1.86	7.32	Charlot River	5,700	257.1	2.85	5.20
Bearspaw	18,000	128.6	2.17	7.87	Interlakes	5,600	257	1.09	3.84
Taltson	18,000	150	2.39	7.92	St. Marys (New)	5,333	80	2.18	7.90
Tenkiller Ferry 1-2	17,895	150	1.51	6.78	Menihek 1	5,000	150	1.32	4.93
Jones Bluff 1-4	17,895	72	1.37	11.99	Three Sisters	4,000	277	1.64	3.84
Whitney 1-2	16,667	128.6	1.60	10.06	Inginiyalaga 3-4	3,500	333.3	1.53	3.23
Fort Peck (1st) 2	16,667	164	1.61	7.77	Mayo	3,000	450	1.30	3.05