LETTER REPORT
ON
PLANT WITH 35 MW UNITS

BURFELL PROJECT

BY THE
HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED FOR
THE STATE ELECTRICITY AUTHORITY
GOVERNMENT OF ICELAND
MAY 1963

LETTER REPORT

ON

PLANT WITH 35 MW UNITS

BURFELL PROJECT

BY THE

HARZA ENGINEERING COMPANY INTERNATIONAL

PREPARED FOR

THE STATE ELECTRICITY AUTHORITY

GOVERNMENT OF ICELAND

MAY 1963

HARZA ENGINEERING COMPANY INTERNATIONAL
CONSULTING ENGINEERS
RIVER PROJECTS

OFFICES
TEHRAN, IRAN
BAGHDAD, IRAQ
SAN SALVADOR, EL SALVADOR
TEGUCIGALPA, HONDURAS
BANGKOK, THAILAND
VIENTIANE, LAOS
LAHORE, WEST PAKISTAN
AMMAN, JORDAN
TAIPEI, TAIWAN

REPRESENTED IN THE UNITED STATES BY
HARZA ENGINEERING COMPANY
CHICAGO, ILLINOIS

May, 17, 1963

CABLE ADDRESS "HARZINT"

ADDRESS REPLY TO
HARZA ENGINEERING COMPANY
FOR THE ACCOUNT OF
HARZA ENGINEERING COMPANY INTERNATIONAL
400 WEST MADISON STREET
CHICAGO 6, ILLINOIS

TELEX NUMBER CG 1-4385

The State Electricity Authority
P.O. Box 40
Reykjavik, Iceland

Subject: Burfell Project
35 MW Units

Gentlemen:

Introduction

We have prepared a study and estimate involving an increase in generating unit size from 30 MW to 35 MW for the Burfell Project. The study was based on the results presented in our Supplementary Report of April 19, 1963 wherein staged development was considered. However, the construction Stages have been redesignated Stages I - 35, II - 35, and III - 35, respectively.

Our recent preliminary studies with respect to the use of Thorisvatn as a storage reservoir to serve for ice sluicing and to firm the flows at Burfell have indicated:

1. An eight-unit plant totaling 240 MW will require the Kaldakvisl Diversion Works and full utilization of the Thorisvatn storage potential.

2. A somewhat expanded Thorisvatn Initial Storage at relatively small incremental cost might justify economically an installation at Burfell totaling about 210 MW.

3. The great incremental cost of (1) over (2), above, for only an additional 30 MW at Burfell can hardly be justified. The cost of the fuller Thorisvatn Storage must be spread over power installations at other plants also.

A total of 210 MW at Burfell with 30 MW units would require seven units, a somewhat inconvenient odd number. It is more feasible and economical to increase the unit size to 35 MW and provide six units to achieve the total of 210 MW. Alternatively, it is not unreasonable to provide two 30 MW units initially and four 37.5 MW units in subsequent installations. The total cost for the ultimate 210 MW would be little different with either alternative so long as expansion plans were properly considered initially.

In brief, it appears that the optimum plant size at Burfell is on the order of 200 MW or slightly more. Greater installations would require substantial storage, the costs of which must be spread, in appropriate part, over other Projects on the Thjorsa and its tributaries. Conversely, the unit costs for power and energy at Burfell increase for installations smaller than this optimum. This situation is true even when the cost for Thorisvatn Initial Storage is included for installations between, say, 120 and 210 MW. This conclusion, however, is based on flow data which may not be very reliable for critical low flow periods. Further, the requirements for ice sluicing cannot be established definitely at this time, though some indications may be received as a result of model tests. It is expected that more reliable data will become available through the early operational years and as more flow data is accumulated with special reference to accuracy during low flow periods. In the meantime, it now appears that the development at Burfell should be aimed at achieving a total rated installed capacity of about 210 MW prior to proceeding with the next generating station in the Thjorsa Basin. Further expansions at Burfell are feasible but require substantial upstream storage.

Project Features

The same general engineering design criteria were used for the Stages of the Burfell Project with the larger 35 MW units as for the Stages with 30 MW units. Accordingly, we made the following changes in the basic dimensions of the structures as compared to those in the Supplementary Report of April 19, 1963:

1. Length of Intake increased by three meters
2. Corresponding increase in width of Diversion Canal
3. Increased pressure shafts (penstocks) from 3.8 to 4.1 meters
4. Unit spacing increased by 0.5 meters to 14.0 meters

5. Width of Machine Hall increased by 0.5 meters
6. Width and height of Draft Tubes increased by 0.5 meters
7. Area of Surge Chamber increased by 15 percent
8. Nominal diameter of Tailtunnel increased from 7.5 to 8.0 meters
9. Corresponding increase in Portal Structure and Tailrace Canal

The increase in the unit rating also required some minor increase in the size and ratings for Accessory Electrical and Miscellaneous Powerplant Equipment. The main power transformers were also increased in rating to correspond with the generating units. No increases were considered necessary in the remainder of the Substation. The Transmission Line is considered adequate in capability for the increased installation.

No increases were provided in the Thjorsa Diversion Features. In theory, the capacities of the Diversion Inlet and Canal should be increased about fifteen percent. However, the increase in design velocities without charge in their dimensions is not great and is probably not critical. None of the other features would require any increase in magnitude.

The size of the Outlet Works for the Initial Thorisvatn Storage should be increased somewhat to provide some additional storage and a greater flow rate at minimum drawdown as compared to the structures included in Appendix D, Volume II of the Burfell Project Planning Report of February 1963. The unreliability of the low flow data makes it difficult to establish accurately as to how large this increase should be. However, within reasonable limits the capacity of the Outlet Works and the Storage Volume can be increased at relatively small incremental cost. Our present judgement is that about $ 2,000,000 should be allowed for the Total Investment for Thorisvatn Initial Storage as an addition to the third Stage of Burfell Project construction with 35 MW units.

Capital Costs

The cost of the Burfell Project with 35 MW units was reestimated on the same general bases as presented in the recent Burfell Project Reports. Details of cost are shown on Table 1, attached, for the

Production and Transmission Plants. This Table also shows a comparison with the costs for the Burfell Project with 30 MW units presented in the Supplementary Report of April 19, 1963.

Table 2, attached, shows the estimate of Project Investment by Stages accomplished on the same general bases as for the plant with 30 MW units as shown on Exhibit S-B (or S-8, sheets 1 and 2) of the Supplementary Report, but with $ 2,000,000 included with Stage III-35 for Thorisvatn Initial Storage. Table 2 shows that the unit cost per rated installed kilowatt is, for each Stage, less than that for the plant with 30 MW units except for the last Stage wherein the Investment in Thorisvatn Initial Storage has been added. Even with this burden the unit cost for the complete plant including Thorisvatn is less than with 30 MW units without any Initial Thorisvatn Storage. On the other hand, it is almost certain that some degree of Initial Thorisvatn Storage should be included with Stage III involving 30 MW units. This addition would make the selection of 35 MW units even more favorable overall on such a comparable basis.

The construction of the Burfell Project with 35 MW units can be substaged readily with separate installation of individual units in each Stage. This procedure would be the same as outlined in the Supplementary Report for the similar possible plan. We estimate that the Investment required for the second unit of each Stage would be about $ 1,250,000. It may be assumed that the power and energy produced by each Stage may be divided approximately equally between each of the two units, but somewhat less for the last unit of Stage III-35.

Annual Costs

The estimated annual cost in thousand United States Dollars for items not controlled by financing terms, computed on the same basis as in the Supplementary Report, is as follows:

Item	Stage I-35	Stage II-35	Stage III-35
Operation and Maintenance	230	200	155
Reserves and Water Rights	180	125	115
Total	410	325	270
Cumulative Total	410	735	1005

Power and Energy

The peaking power in kilowatts delivered at the Reykjavik Receiving Substation from the Burfell Project as each successive Stage is completed, together with the increment over the plant with 30 MW units, was estimated to be as follows:

Stage	Delivered Power	Increment over plant with 30 MW Units
I-35	69,000	10,000
II-35	136,000	20,000
III-35	205,000	30,000

The delivered average annual primary energy in million kilowatthours, computed on the same general basis as in the Supplementary Report, was estimated and is compared with the delivered production from the Burfell Project with 30 MW units as follows:

No. of Units Installed	Size of Individual Units		Increment
	35 MW	30 MW	
2	550	475	75
4	1085	940	145
6	1575	1375	200

The increment of delivered energy in million kilowatthours on this same comparative basis would be as follows:

No. of Units Installed	Size of Individual Units	
	35 MW	30 MW
2	550	475
4	535	465
6	490	435

The above energy estimates for Stage III-35 do not include any allowance of firming energy from Thorisvatn Initial Storage. It is expected that some increment, however, would be available, and that not all of the stored water would be required for ice sluicing. Thus, the estimates for Stage III-35 are somewhat conservative.

The annual energy requirement in million kilowatthours for an aluminium potline operating at the usual 98 percent load factor for several normal peak load requirements would be as follows:

Peak Load-KW	Annual Energy
60,000	513
59,000	505
58,000	496
57,000	487

On this basis it can be seen that each Stage of two units for the Burfell Project comes nearer with 35 MW units than with 30 MW units to providing the energy requirements for one aluminium potline.

Primary Energy Costs

The unit cost of primary energy for each Stage and as each Stage is completed was estimated on the same general basis as utilized in the Supplementary Report. The unit cost of energy was determined for annual debt service expressed as five, seven, and nine percent of estimated Total Investment. Thorisvatn Initial Storage was included with Stage III-35 as discussed above. These computations are shown on Table 3 and presented graphically on Exhibit I, both attached. Exhibit 1 represents a revision of Exhibit S-C of the Supplementary Report of April 19, 1963. Thus, a comparison is shown between plants with 30 MW units and plants with 35 MW units.

Summary & Conclusions

The above analyses show that the Burfell Project is more favorable on the unit energy cost basis in all Stages of development with 35 MW units than with 30 MW units on a comparable basis, i.e., Thorisvatn Initial Storage included with the last Stage. The increased economy, however, is not great. Further, consideration has not as yet been given specifically to the coordination and overall economy which units of this larger size might have with respect to load, with or without an aluminium smelter.

Nevertheless, the study points to an ultimate station of about 210 MW as representing about the optimum for the Burfell Project. This should have verification as more reliable flow data, especially during low flow periods, becomes available. On the other hand, an ultimate station of 180 MW appears to be slightly too small. The

best size may lay somewhere between these two totals. It is reasonable to assume that costs and benefits would both vary on about a straight line basis from the values presented in the Supplementary Report for the 180 MW plan and the values presented above for the 210 MW plan.

It is our opinion at this time that the future planning of the development of the hydroelectric potential at Burfell should proceed pointed towards a plant installation totaling about 200 MW or slightly more prior to the time that large upstream controlled storages are added. Further, no generating unit rated less than about 30 MW should be installed. On the assumption that all six units would be sized equally, a unit rating up to about 35 MW appears appropriate. Equal sized units ranging from 30 to 35 MW each might be selected with relatively little difference in overall ultimate economy. The final selection on this equal size basis would probably be determined principally by considerations with respect to future loads. The time of any addition of a future large industrial load would, of course, have an important bearing. Within reasonable limits there could be increases in unit sizes by pairs in the last two Stages over, say, 30 MW in the first Stage. This variable procedure, however, is not usually considered desirable.

Please advise of any further studies you may desire with respect to unit sizes larger than 30 MW each at the Burfell Project.

Very truly yours,

HARZA ENGINEERING COMPANY
INTERNATIONAL

C.K. Willey

C.K. Willey
Vice-President

Encl: Tables 1, 2, & 3
Dwg 290 P 101

TABLE I

BURFELL HYDROELECTRIC PROJECT

COST ESTIMATE-SUMMARY

(in U.S. Dollars)

STAGED DEVELOPMENT

PLANT WITH 35 MW UNITS VERSUS PLANT

WITH 30 MW UNITS

Item	Estimated Cost					
	STAGES					
	I	I-35	II	II-35	III	III-35
POWER PLANT STRUCTURES						
Powerstation	1586.900	1659.900	698.000	755.000	263.000	288.000
Access Tunnel	999.100	999.100	-	-	-	-
Subtotal	2586.000	2659.000	698.000	755.000	263.000	288.000
RESERVOIR, DAM AND WATERWAYS						
Burfell Reservoir	70.000	70.000	-	-	5.000	5.000
Bjarnalaekur Dike	1000.000	1000.000	160.000	160.000	-	-
Right Bank Dike	-	-	130.000	130.000	-	-
Left Bank Dike	-	-	-	-	530.000	530.000
Diversion Canal	297.500	297.500	400.000	400.000	-	-
Bjarnalaekur Canal	438.000	438.000	-	-	-	-
Diversion Weir & Inlet	676.050	676.050	808.350	808.350	381.500	381.500
Approach Canal	150.000	155.000	-	-	-	-
Sluiceway	235.050	235.050	-	-	-	-
Dike at Sluiceway	89.500	89.500	-	-	-	-
Intake	253.200	269.600	340.850	364.950	71.500	77.000
Penstocks	263.000	291.500	263.000	291.500	263.000	291.500
Tailrace Surge Chamber	255.800	286.800	517.800	573.200	-	-
Tailrace Tunnel	2876.900	3271.000	-	-	-	-
Tailrace Canal	190.000	215.000	-	-	-	-
Subtotal	6795.000	7295.000	2620.000	2728.000	1251.000	1285.000
TURBINES AND GENERATORS	1153.000	1370.000	1153.000	1370.000	1153.000	1370.000
ACCESSORY ELECTRICAL	353.000	391.000	225.000	247.000	240.000	260.000
MISCELLANEOUS POWER PLANT EQUIPMENT	383.000	407.000	146.000	160.000	145.000	159.000
ACCESS ROADS AND BRIDGES	340.000	340.000	80.000	80.000	130.000	130.000
OPERATORS VILLAGE AND GENERAL PLANT	165.000	165.000	95.000	95.000	40.000	40.000
SUBTOTAL PRODUCTION PLANT	11775.000	12627.000	5017.000	5435.000	3222.000	3532.000

TABLE I

(continued)

	Estimated Cost					
	STAGES					
	I	I-35	II	II-35	III	III-35
TRANSMISSION PLANT						
Búrfell Step-up Substation	266.000	278.000	460.000	471.000	368.000	379.000
Transmission Line Burfell-Reykjavik	1540.000	1540.000	-	-	-	-
Reykjavík Receiving Substation	76.000	76.000	313.000	313.000		
SUBTOTAL TRANSMISSION PLANT	1882.000	1894.000	773.000	784.000	368.000	379.000
SUBTOTAL DIRECT COST	13657.000	14521.000	5790.000	6219.000	3590.000	3911.000

TABLE 2

BURFELL HYDROELECTRIC PROJECT

STAGED DEVELOPMENT

COST ESTIMATE-SUMMARY

(in U.S. Dollars)

PLANT WITH 35 MW UNITS

Item	STAGES I-35	II-35	III-35
SUBTOTAL PRODUCTION PLANT*	12,627,000	5,435,000	3,532,000
SUBTOTAL TRANSMISSION PLANT*	1,894,000	784,000	379,000
SUBTOTAL DIRECT COSTS*	14,521,000	6,219,000	3,911,000
Contingencies	1,969,000	771,000	409,000
TOTAL DIRECT COST	16,490,000	6,990,000	4,320,000
Engineering and Supervision	1,320,000	560,000	350,000
Preliminary Investigation Cost	510,000	-	-
SUBTOTAL	18,320,000	7,550,000	4,670,000
Extra Cost Incremental		380,000	230,000
CONSTRUCTION COST	18,320,000	7,930,000	4,900,000
Interest During Construction	1,780,000	570,000	350,000
Thorisvatn Initial Storage	-	-	2,000,000
STAGE INVESTMENT COST	20,100,000	8,500,000	7,250,000
RATED INSTALLED CAPACITY KW	70,000	70,000	70,000
Unit Cost-Dollars Per Rated Installed Kilowatt	288	122	104
CUMULATIVE PROJECT INVESTMENT			
Stages I-35 plus II-35		28,600,000	
Stages II-35 plus III-35			15,750,000
Stages I-35 plus II-35 plus III-35			35,850,000
CUMULATIVE INSTALLED CAPACITY KW		140,000	210,000
Cumulative Unit Cost-Dollars Per Rated Installed Kilowatt			
Stage I-35 plus II-35		204	
Stages II-35 plus III-35			113
Stages I-35 plus II-35 plus III-35			171

*From Table 1.

TABLE 3

BURFELL HYDROELECTRIC PROJECT

STAGED DEVELOPMENT

PLANT WITH 35 MW UNITS

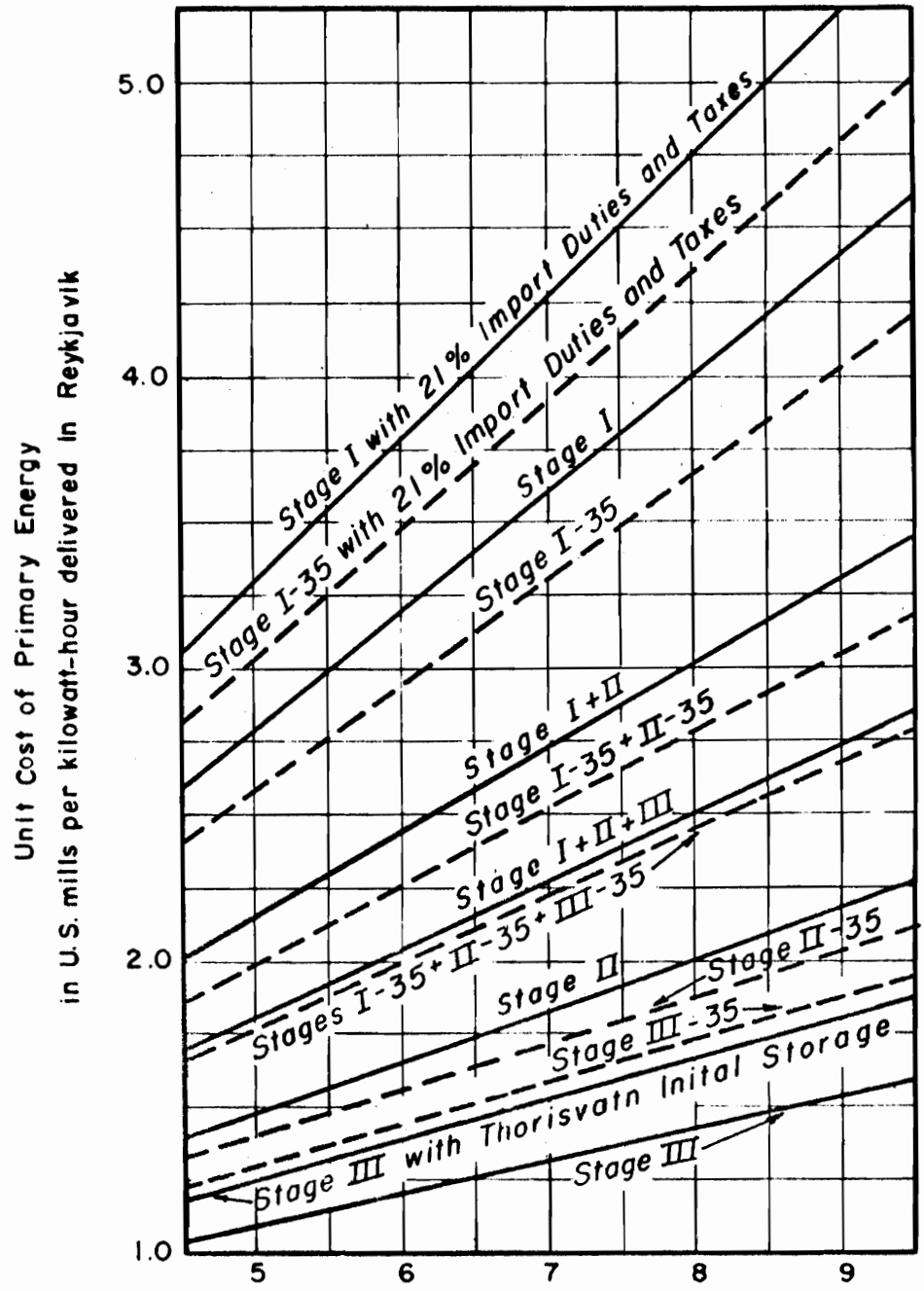
ESTIMATED UNIT COST OF ENERGY

STAGE-I-35		Percent of Debt Service		
		5	7	9
O & M, Reserves, etc.	$1000	410	410	410
Debt Service	$1000	1005	1410	1810
Total	$1000	1415	1820	2220
Annual Energy	MKwh	550	550	550
Cost of Energy	US Mills/Kwh	2,58	3,31	4,04
STAGE II-35 (Incremental)				
O & M, Reserves, etc.	$1000	325	325	325
Debt Service	$1000	425	595	765
Total	$1000	750	920	1090
Annual Energy	MKwh	535	535	535
Cost of Energy	US Mills/Kwh	1.40	1.72	2.04
STAGE I-35 plus II-35				
O & M, Reserves, etc.	$1000	735	735	735
Debt Service	$1000	1430	2000	2570
Total	$1000	2165	2735	3305
Annual Energy	MKwh	1085	1085	1085
Cost of Energy	US Mills/Kwh	1,99	2,52	3,05
STAGE III-35 (Incremental)				
O & M, Reserves, etc.	$1000	270	270	270
Debt Service	$1000	360	510	650
Total	$1000	630	780	920
Annual Energy	MKwh	490	490	490
Cost of Energy	US Mills/Kwh	1,29	1,59	1,88
STAGES I-35 + II-35 + III-35				
O & M, Reserves, etc.	$1000	1005	1005	1005
Debt Service	$1000	1795	2510	3225
Total	$1000	2800	3515	4230
Annual Energy	MKwh	1575	1575	1575
Cost of Energy	US Mills/Kwh	1,78	2,23	2,69

TABLE 3
(Continued)

STAGE I-35 WITH 21% DUTIES AND TAXES		Percent of Debt Service		
		5	7	9
O & M, Reserves, etc.	$1000	450	450	450
Debt Service	$1000	1210	1700	2190
Total	$1000	1660	2150	2640
Annual Energy	MKwh	550	550	550
Cost of Energy	US Mills/Kwh	3,02	3,91	4,80

EXHIBIT I



LEGEND:

——— 30 MW Units

– – – – 35 MW Units

NOTES:

No allowance made for income from sales of secondary energy.

Import duties and taxes not included except as noted.

Stage III-35 includes Thorisvatn Initial Storage, but no allowance for any increase in firm energy.

THE STATE ELECTRICITY AUTHORITY ICELAND	
BURFELL PROJECT	
UNIT COST OF ENERGY	
HARZA ENGINEERING COMPANY INTERNATIONAL	
PREPARED BY HARZA ENGINEERING CO., CHICAGO APPROVED	
DATE MAY, 1963	DWG. NO. 290P 101