HYDRO-ELECTRIC POWER STATION DESIGN

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A THESIS

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PREFACE.

The subject of "Hydro-Electric Power Station Design" has herein been presented in two parts :- the first - a brief treatise on the general principles and important factors, and the second - an application of these to a particular case.

In Part I. is given a general statement and analysis of the important factors entering into the design of such power generating stations.

In Part II. the actual design of a station for a particular location is undertaken. This proposed station to be located on the Snake River in the south-central part of the state of Idaho, and to receive its water supply from the Malad - a tributary of the Snake River.

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T A B L E   O F   C O N T E N T S.

L I S T   O F   I L L U S T R A T I O N S.

Part I.

A Brief Treatise on the General Principles and Important Factors Entering Into the Design of Hydro-Electric Power Generating Stations.

Hydro-Electric Power Station Design

Introduction.

A consideration of the subject of "Hydro-Electric Power Station Design" entails a discussion of the location of the market for sale of power, nature and extent of the water supply of the source of power, auxiliary construction for water handling, location, construction and equipment of generating station, transmission and distribution of energy.

The General Problem.

Electrical energy is now in nearly universal demand. The amount of this commodity that is made use of in any section of country varies within wide limits. For its common usages - in power and lighting - this variation is nearly directly with the population, though there is a constantly increasing demand for it in railway work - outside of centers of population. With the increased price of coal, as well as for other disadvantages inherent in steam production,- other means than indirectly from coal,of generating electric current,

are being rapidly sought and utilized. Chief among these, in present importance, is the water power of natural sources.

As these cannot be located where wanted - as can steam plants - but must be taken where found, the general problem becomes one of relation between location of <u>market</u> for power and the <u>source</u> of power generation. Ordinary commercial principles would usually dictate that a power development be carried forward only after a demand had arisen for power in a given locality. This is merely a creation of supply to meet demand. There have been, however, in recent water power developments - numerous cases of the opposite procedure to this. In such projects, water powers - especially favored by location or proportion or both - have been developed first and the market created afterwards, in range of transmission. This constitutes a forcing demand in such localities - by the creation of an attractive supply.

The allowable distance between the point of generation of power and the point of consumption is therefore limited by the range of economic and safe transmission of the energy. As a result of improving methods and equipment this distance is gradually lengthening. Present practice does not much exceed one hundred miles for this as a maximum figure.

Outside of matters of relative location of market for power and the source of power supply, there are several important points to be considered under the "general problem". First among these arises the question of the ability of the water supply to satisfy the market for power; that is, whether the maximum continuous hydraulic power of the source is sufficient to meet the demands of the market. The assumption is made that the "water rights" for this amount are obtainable. If the amount of hydraulic power thus covered is not sufficient, then the advisability or necessity of

an auxiliary steam plant must be considered. Next comes a consideration of the character of the load That is, the purpose for which the power is to be used,- whether for lighting, for railway work, for miscellaneous power purposes or for a combination of these. If the latter, then the approximate proportion of each.

All of these points must be reviewed under a general survey of a water power development. For further consideration, the more detailed factors influencing a project must be taken up. These are outlined in what follows.

The Water Supply.

The very existence of a hydro-electric power generating station depends upon its water supply. Obviously then, the continuity and comparative uniformity of flow of this should be at least reasonably assured.

Power sources for such developments at present are chiefly confined to the fall and flow of

streams. The two main factors governing these developments are the "head" and the volume. The first quantity represents the difference in elevation between the surface of the water in the supply reservoir and in the tailrace: that is, the difference in height of the water before and after its potential energy has been utilized. This factor is commonly given in "feet. The second quantity is the flow,or volume of water per unit of time which is available for use at the given head. This factor is usually expressed in "second-feet"- an abbreviated expression for "cubic feet per second".

The available head, for any project, is -once it has been decided upon - practically constant. It may be ascertained by means of a careful topographic survey of the stream. On the other hand, however, the second factor - namely the "flow" - is, owing to the variable quantities upon which it depends,- quite likely to be anything but constant. It is this factor which gives rise to most of the difficulties to be met in hydro-electric power sta-

tion work.

A more careful investigation into the nature of this quantity - "flow" - will reveal the fact that it is liable to change from day to day, season to season and even from year to year. Primarily, it depends upon the size, contour, vegetation and soil of the drainage area of the stream, as well as upon such climatic conditions as rainfall, temperature and barometric pressure. In the calculation of this quantity both the greatest care and the most conservative judgement should be used. Even with these detailed precautions, unusual conditions may arise at times, after the project is completely installed,- conditions of great excess, or the exact opposite, in the water supply. The result being that a large proportion of the investment, possibly the entire amount, will be rendered valuless. Such serious happenings have been known to take place and nothing should be left undone in the way of precaution. Therefore all records that it is possible to obtain of the

flow of the stream in question should be carefully examined and compared, as well as careful attention paid to all of the factors influencing it. The object of such researches throughout, being to obtain as accurately as possible, first - the actual minimum that can be reasonably expected from the stream in point of constant flow, and second, the points of maximum discharge - together with means of conserving the energy of such surpluses of water.

Foremost to be considered is the drainage area. This should be investigated from the source of the stream and its tributaries to its mouth. Area, contour, vegetation, soil and rainfall should be considered. Other factors the same, the larger the area drained, the greater the "run-off" of water. The contour, vegetation and soil manifestly influence such quantities as absorption of rainfall and the evaporation of surface waters - with a subsequent influence exerted on the resulting "run-off". The effect of rainfall on stream flow is positive though not absolute, as it is greatly

affected by the above outlined climatic conditions. The dry-weather flow of a stream is not so much influenced by the total annual rainfall as it is by the distribution of such rainfall as occurs throughout the year. In this case,as in all cases of relation of rainfall to stream flow, no absolute and general rule can be formulated, the problem of each watershed being distinctive. However there are some considerations common to all cases and these will be here briefly taken up.

In the first place, what may be termed the "water year", begins approximately with the month of December and ends approximately with the November following. This is divided into three periods: the first six months constituting the "storage" period, the next three months - the "growing" period, and the remaining three months - the "replenishing" period. During the first period the winter snow and the spring rains saturate the ground to a considerable depth, a large amount of water being held in storage in lakes, swamps and forests as

well as in the soils,gravels etc. At this time in the year a heavy rainfall finds a quick response in large stream flow, for the saturated ground rejects further water, and the water runs rapidly from the surface. That part of the stored water of this period which lies above the level of the bed of the stream, within the boundaries of its water-shed, becomes available for supplying the stream as well as for the purposes of surface evaporation and the sustaining of plant life. These waters will supply a certain part thereof to the stream, regardless of the rainfall, even maintaining a flow in the stream for some months without any rainfall.

During the "growing" period the ground water furnishes practically the entire supply to the flo of the stream, the only additional part coming from an occassional rainstorm. In some cases so depleted does the ground water become by the end of August that even a very heavy rain will make no perceptible difference in the stream flow, the

ground absorbing the entire amount of the precipitation.

During September, October and November the ground begins to receive its store of water, and with favorable rainfalls, it becomes saturated during the "storage" period following. The stream flow is a constant drain on this supply, but in addition to this there is a loss of water falling on the watershed due first to evaporation and second that amount taken up by plant life.

Having thus discussed the subject of Drainage Area and the influence of its various components on stream flow, we come to a consideration of the stre itself. No matter what the more or less theoretical factors influencing the stream flow may be, we have finally to deal directly with the actual volume of water flowing in the stream. To measure this quantity there are three general methods, any one of which may be used: the choice,in any case, depending upon local conditions, the degree of accuracy desired, the funds available, and the length

of time that the record is to be continued.

The first general field method for obtaining the value of stream flow is by measurement of the slope and cross section and the use of Chezy's and Kutter's formulas: the second method is by means of a weir: and, the third by measurement of the velocity of the current and the area of cross section of the stream. Where conditions will permit, the second method offers the best facilities for determining the flow.

The greater the period of time for which this data is available,- showing past performances of the stream under various conditions of season and climate- the more accurately can its future probable flow be predicted. As it is with this quantity of "future flow" that the proposed plant will have to reckon, calculations for it should, if possible, be based on data for at least a number of consecutive years previous.

A very convenient way of considering this is

to plat, for each year upon which data is available, a curve showing the relation between the time of the year and the flow. The abscissae represent the days of the year, division points locating the different months, and the ordinates - the correspon ing flow in "second-feet". A scale of theoretical hydraulic horse power may be marked off on the axis of ordinates, this merely representing a constant times the"second-feet" of flow,- the constant depending upon the "head" and the weight of water. From this scale may be read directly the power possibilities of the stream at any given time. A straight line drawn parallel to the axis of absciss through the lowest point on the curve, will show the maximum power to be realized from the stream <u>throughout</u> the year. If the physical conditions of the channel and banks of the stream will permit of the construction of a properly proportioned dam together with retaining walls (if necessary), then the whole or at least a part of the water represent ed by the"peaks" on the time-flow curves may be

stored up as "pondage", and drawn off at times of "low water", the resulting maximum constant flow being thus increased. The comparison of the time-flow curves for a number of years,on the same strea will show the variation to expect - at least as possibilities- from year to year.

From a proper consideration ,then, of the fore going points - influencing the water supply of a hydro-electric development - may be obtained a fair calculation of the power to be expected from the source. From this,we are lead to a consideration of the exact location of the plant.

Exact Location For Plant.

The approximate location of a hydro-electric project being determined by means of the factors of the "General Problem", namely the market for sale of the energy and the source of the water powe there remain but a few points which will decide the exact location of the plant.

The question of "water rights" must be settle

By this is meant the obtaining from the State of the right to use, for power generating purposes, a certain number of second-feet of water from the stream in question. After this, comes the matter of real estate on which to locate the power house and auxiliary water controlling works. This is, however, usually a minor point as such property is generally some distance from centers of population, and hence its value is comparatively small.

Outside of these considerations, the exact location of the plant should be such as to realize the greatest efficiency from the two controlling factors in any project, namely the "head" and the volume of water. The most available head, considering total fall and the possibilities of back-water, and the arrangement permitting of the most economic use of the volume of the water, considering the desireability or necessity of storage supply - are the two factors to be sought. With this decided we pass to a discussion of the component parts of a

hydro-electric power generating project.

Parts of the Project.

With the exact location of the plant settled, the general lay-out of the auxiliary water controlling works must be determined upon. The devices best adapted to conveying the water from the source of supply to the wheels - form a question, peculiar to each individual case. However, they consist - in general - of a reservoir, either a part of the stream or apart from it; a conducting pipe-line from this to the power house, or in the case of an open penstock type - a forebay; and, a tail-race. In this work, such parts as dams, intakes, penstocks gates and tail-races must be considered, and are here treated of briefly.

Dams.

For water-power work, there are two kinds of dams most used - depending upon the material of their construction, the first - the earthen, and the second - the masonry dam. Of these two classes

the failures of earthen dams have been the most numerous, the cause being either that there was not the proper length of spillway, or that the outlet pipes were not properly laid in the dam. The requirements for stability of any dam are, that it be strong enough to withstand the pressure of all water that it holds back, that it withstand leaks, and that it afford proper spillways and sluice-gates.

In the construction of an earthen dam, three things must be considered: first, the conditions must be such that the maximum flood that has ever occurred at the site can be taken care of during the building of the dam;second - the water must never top the embankment of the dam, - it being either led around the end of the dam or through some new channel; third - the proper soil should be used in the construction of the dam. If conditions are such that the flood waters likely to arise cannot be carried around the end of the dam during its construction, then the earthen dam should never be

used.

Any soil used in the construction of an earthen dam should be tested for quicksand, and if any traces are found the soil should be discarded. Soils having an angle of repose of less than twenty degrees when placed in water should not be used. The best soils for use are those containing enough clay to give the required water-tightness and binding quality,- too much of this ingredient should be avoided as it swells on becoming wet and shrinks on drying. If,during the construction the materials are dampened, cracks and leaks are less liable to occur. If the material at hand is of different grades, the best should be placed on theupstream side, gradually changing to the more porous toward the center of the construction.

The profile of an earthen dam will depend upon the height of the dam. The slopes will depend upon the angle of repose of the material used, it being usual to make the inner or upstream side

flatter than the outer or downstream side, as earth when wet has a flatter slope than when dry.

Where a masonry dam is constructed more attention must be paid to the foundation than is necess ary in the case of an earthen dam as any settling of the masonry will cause cracks. With high masonry dams the foundations are usually made of solid rock. The superiority of the masonry over the eart en dam lies in the facts that it can be made more durable, can be more precisely designed, and better protected from flood waters, owing to the safer construction it offers for the laying of the outlet pipes. For all dams of any height, masonry construc tion is to be preferred.

The shape of a masonry dam will depend upon the head of water for which it is designed, for low dams the cross-sectional shape usually being trapezoidal, but for high heads the sides are usually curved for the purpose of saving material.

The reinforced concrete dam has some advantag

that the masonry dam does not possess. It can be made more stable than a masonry dam of the same dimensions. The materials can be distributed to better advantage and therefore there will be a saving in cost. The interior of the dam can be inspected, it can be constructed more rapidly and does not require such good foundations as do masonry dams. In many cases where a reinforced concrete dam is constructed the power house is built into the dam, thus greatly reducing the cost of the project.

One factor in the building of concrete and masonry dams which does not affect the earthen dam is the effect of ice. In countries having cold winters the expansion of ice is liable to be great enough to rupture the dam, masonry more so than conrete.

"Intakes" lead from the dam, being either submerged or at the level of the water. The flow through them being controlled by gates which are either machine or mannually operated.

Penstocks.

The cheapest form of penstock is the circular wooden stave penstock. The staves should be as fre from knots as possible and should be smoothed on the inside in order to reduce friction and get the maximum efficiency. Where the stave penstock is installed it is common to have all bends and curves in the line of steel pipe, unless the curve be of large radius. Iron hoops or bands are used to hold the staves in place, their spacing depending upon the initial tension, the water pressure, and the swelling of the wood.

Steel penstocks are especially adapted to long pipe lines, as often,in such lines, abnormal pressures are developed due to the sudden shutting-off of the water from the turbines. In order to regulate this pressure, a small reservoir is constructe at the outlet of the penstock, the size of this reservoir depending upon the time it takes to close the turbine gates. In place of the reservoir

a steel standpipe is sometimes used, the water running over the top of the standpipe if the gates be closed too suddenly. If the fall of the pipeline be too great for standpipes, safety valves are placed along the line of the penstock. The life of a steel penstock is sometimes very short due to the rusting of the steel, though this action may be greatly reduced by treating the penstock with hot asphaltum. At the entrance to penstocks, racks should be so placed as to collect all floating objects and not allow them to pass into the pipe. In cases of ice formation these racks may become clogged if the ice is not removed on forming. A large,deep forebay will remedy this trouble, as the water,being quiet here,will freeze over at the beginning of cold weather. Then such anchor ice,as may come into the forebay, will rise to this layer of ice, while the warmer water will circulate below. If the intake to the penstocks be so located as to receive this water, there will be little trouble from ice at the racks.

Tail-race.

This should be deep as it is necessary to have dead water in the race before the wheels are started. As soon as water is discharged from the wheels this will take the place of dead water and thus there will be no resulting loss of head. It is usually necessary to place the wheels at some height above the tail-race, the water after leaving the wheel passing through a draft tube. This draft tube should be air tight and submerged - at its lower end - in the water of the tail-race to prevent any loss in head.

Power House Equipment.

Water Wheels.

These may at once be divided into two classes - impulse wheels and turbines. The former is typified by the Pelton Company's wheel, in which the velocity of a jet of water impinging tangentially upon a disc, carrying buckets around its periphery, transmits to the buckets a part of its velocity.

It can be shown that the efficiency of the transformation is a maximum when the velocity of the moving buckets is one half that of the jet, so that if H is the effective head of the source, for maximum efficiency, the peripheral velocity of the wheel is related to the head by the expression:

$$V' = .5 \sqrt{g H}$$

and the head being assumed invariable, it is seen that for a certain definite speed (imposed by the frequency of the generator), the only variable is the diameter of the wheel and this may be adjusted within certain limits, to conform to the relation above. Thus direct connection of the generator to the source of power is possible, which eliminate the losses in transmission through gearing and the noise incident to its use.

These wheels require that there be sufficient distance between the wheel and the highest point of backwater, to allow for the discharge of the spent water from the buckets of the apparatus, and for

a variable height of back water at different seasons of the year, this involves a serious loss of head. Also, since the action of the machine depend upon the velocity of the jet, which in turn depends on the square root of the head, the Pelton wheel is only available with any great efficiency when the head is great, i.e. above three hundred feet. In general, then, its use should not be considered with heads less than this.

Water turbines are available for the lower heads, since they do not depend entirely upon the velocity for the necessary kinetic energy - the large mass of water obtained may reduce the necessary velocity. These machines are typified by the products of the James Leffel Co., the S.Morgan Smi Co. and many others. Under favorable conditions they give an efficiency of from eighty to eighty-two percent, and may be obtained in the horizontal or verticle form. The verticle type, on account of the reduced friction losses caused by the lesse ed friction in the bearings, gives an efficiency

about three per cent higher than the horizontal type, exclusive of gearing, but due to the fact that gearing is necessary to change the direction of motion, involving a loss of about ten percent, the actual net efficiency is reduced approximately seven percent unless the generators are of the vertical type also. Horizontal wheels are favored because they permit the use of several units on one shaft, and if this number is even, the unbalance of pressure caused by one unit is taken up by the next so that the friction loss is diminished. In order that vertical units may actuate one shaft, this shaft must be horizontal to conform to practical conditions and the use of vertical generators as was noted above, is precluded, and there is also introduced the loss due to the gearing which must be installed.

In choice of prime movers it is therefore necessary to consider:—

1. The available head, which will determine practically the availability of Pelton or turbine

wheels by the condition that for heads above three hundred feet the Pelton wkeel is to be preferred, for heads less than two hundred feet, the turbine, and for intermediate heads, either one indifferently.

2. The type and speed of the units and their capacity, since for generators of large size it may be necessary to install several units on one shaft, which involves the difficulty mentioned above, and the restrictions that limit the generators of the horizontal type.

3. In addition to these conditions, which must hold generally, others are imposed when the head is not constant, that is, when the backwater is variable. In this case the velocity of the wheels will not be constant, and since the generators are practically construtted to operate at a constant frequency, this variation could not be allowed, even if the field rheostat of the machine were capable of taking up the increase or decrease of pressure at the terminals. Also, since a decrease in speed will decrease the output, it would be necessary,

even in the above case, to install a greater capacity than would be required at the normal full-load speed and the disadvantages noted would still be present.

In this case it is necessary to install another wheel is geared with a higher ratio to the line shafting so that when the head is decreased this wheel may be thrown in with the other one, their speed then being a mean between the two and the decrease in output of the first being supplied by the second. If the variations in head are very wide, it may be necessary to install several of these additional wheels and allow them to run idle during the normal operation of the plant. This extra installation of course involves a higher first cost and is to be avoided if possible.

In the choice of the number of units there should be considered the over load capacity of the units so that when one is disabled or shut down the remainder of the plant may carry the load without exceeding the allowable overload rating of each

unit. It is common practice to decide on this rating as 33%, and it then follows that four units are necessary since on may then be cut out and the rest can carry 33% overload and maintain the normal ouput of the plant.

Generators:— The first classification of generators is into the direct and alternating current machines, and the choice is determined by the character of the load and the transmission distance. We assume that this distance is not short enough to warrant the use of direct current, and proceed to consider the features which determine the choice of alternators. The problem for direct current transmission is much simpler, and may be solved by neglecting the factor of frequency.

The conditions determining the frequency are the character of the load and the transmission; for example if the power is to be supplied to synchronous converters the frequency should not exceed forty cycles, and to conform to the apparatus already in stock in the manufacturing concerns, this figure should probably be chosen at twenty-five.

This is also suitable for transmission and power service, but has the disadvantage that incandescent lamps do not operate well at this frequency so that if the lighting load is not concentrated in cities where it may be supplied by synchronous converters it may be necessary to install frequency changers. At sixty cycles this difficulty would be avoided, but converters do not operate at this frequency with any great stability, and the conditions of constancy of service demand that the substation operation be as nearly perfect as possible.

If it is found desirable to use this higher frequency, induction motor-driven generators may be installed for the conversion to direct current, but this eliminates the possibility of compensation for lagging current in the line, and this difficulty may be of considerable magnitude if the line is to supply power to induction motors along the right of way.

A careful consideration of the load to be supplied will therefore be necessary in order to determine the frequency at which the current is to be supplied.

The voltage to be generated by the machines is of little importance if it is to stepped up for transmission, so that this fact must be dter-mined. The highest voltage at which it is practic-able to generate is about 11,000. In deciding upon the transmission voltage it is common practise to figure roughly upon a thousand volts per mile within the limits of safety, which is set at 60,000 volts in this country. We therefore decide that if the distance to which power is to be transmitted exceeds ten or fifteen miles it will desirable to step up the pressure and generate at such a potential that the insulation of the machines will not be in danger nor will the armature be forced to carry excessive current.

It having been decided in the preliminary in-vestigation what will be the capacity of the plant, the next step is the division of units. The same conditions which govern the number of prime movers apply here and we may state that there should be at least four units, a greater number being of course necessary when the output of the plant is so great

that four units of the largest commercial size will not carry the load.

We now have the frequency and capacity of the generators and desire to know the speed at which they will operate. This speed is limited to certain definite values by the limitation to constant frequency so that the r.p.m. must satisfy the relation:

$$60\ f\ /\ p = n$$

where p is the number of pairs of poles and f the frequency. From this relation the following table may be made showing the number of poles for each speed to give the desired frequency and the catalogs of the manufacturers may then be consulted to determine the machine to use. Before settling upon a unit the peripheral velocity of the rotating parts should be calculated in order to ascertain if this value is too high for the safe operation of the machine. If this is the case it will be necessary to choose a machine with a greater number of poles and a slower speed.

The generators should if possible be direct-connected to the prime movers to eliminate any friction losses in the transmission and this fact necessitates a consideration of the speed of the wheels. This speed is determined by the effective head, and in the case of the Pelton wheel it was shown that the diameter of the wheel could be varied withinn certain limits to compenstae for any disagreement between these twp speeds. In the case of the turbine, however, this compensation is not always possible, although the manufacturers have in stock a great variety of wheels which will generally give the desired relation. If this cannot be obtained it will be necessary to gear the wheels and the generator can then be made to run at any speed, the desired frequency being obtained by the ratio of the gears.

Exciters:—From two to three percent of the output of the plant is required for the excitation of the units, so that this much must be added for

[illegible]

[illegible]

[illegible]

the gross output of the plant if the initial calculations are sufficiently close to warrant consideration of quantities of this magnitude. The exciter plant is the weak link in the system and great care must be exercised in the installation of the units. Several facts may be noted in this connection.

1. There should be two independent sources of excitation which may be readily interchanged so that in the event of one becoming disabled the operation of the system may not be suspended for any considerable period.

2. The prime movers or other apparatus driving the exciters should also be independent and capable of operating in parallel so that in the event of the failure of one system the other may be automatically thrown into service without the delay incident to the manual operation of the necessary switches. By this is meant that the exciters should be provided with reverse current

relays so that in case one of the prime movers fails and the generator thereby becomes motorized the other may pick up the load while the first is automatically cut off from the exciter bus. This means that each system must be capable of carrying all the excitation necessary for the plant at any time, and since the breakdown of apparatus usually occurs at times of heaviest load, this consideration is of fundamental importance. In water-power stations the sources of power may be water-driven wheels for the operation of one system and motors for the other. In this case the motor-driven apparatus must be kept constantly in operation, since if this were not the case the failure of the water-driven exciters would disable the plant. At times of light load, however, it will be safe to operate the plant with but one set of exciters, since the possibility of the break-down of apparatus is slight and more is to be feared from the mistakes of the

operators than from faults of the machines.

Transformers:—It having been decided that there will be a definite number of phases—usually three—and the transmission voltage being known, the transformer problem becomes simply a phoice between the adoption of three single-phase transformers connected up to give the desired relation of e.m.f's or one three-phase transformer for each unit. The conditions influencing the choice are as follows:

1. The distance from the nearest shipping point to the power station—this enters in because of the fact that large transformers are more difficult to handle than small ones, and if, as is usually the case, the power house is located in a mountainous country, the smaller units would probably be chosen, since the cost of transportation will overbalance any saving in first cost.

2. The facilities for the handling of the apparatus at the power station, such as cranes, labor, etc. The use of the larger units of course

makes necessary a larger crane.

3. The necessity for a spare unit. In the case of three single phase units the connection may be so made that any one of the transformers in the station may be disconnected if injured and the spare put in its place by means of air-break disconnecting switches. If three units are employed a three phase unit may be used as a spare and the increased cost would make an installation of the single phase units desirable. This consideration vanishes when the size of the station is great or the units numerous, since the additional complication of circuits due to the installation of disconnecting switches more than balances the extra cost of the three phase unit.

4. If one of the single phase units becomes burned out it may be removed, but in the other case the whole transformer will need to be removed unless it is connected delta and allowed to operate with a V-connection at 58% of its former output.

The large units are in general desirable if the objections mentioned above do not operate, for they are more compact, all the coils in one case and the installation is less complicated, also the first cost is less. A disadvantage is, that since the surface of a transformer and its output do not vary uniformly, but the surface less rapidly, the cooling of the larger sizes will be a more serious problem. This however may be accomplished quite readily by the use of fans for circulating the air through the coils.

Instruments and Wiring:— These switchboards may be separated into two parts, the exciter board and the mainboard, and these may be concentrated in one position or separated, according to the size of the station. When the size is sufficient to warrant the constant attention of two operators, the exciter board may be isolated and located near the exciter units, the other being placed in a gallery. When this arrangement is adopted one operator may take charge of the exciter board and look after the units on the main floor while the

other confines his attention entirely to the operation of the lines and units. Where theplant is used to supply a large number of lines it is preferable to have the oil switches located in a room by themselves with an attendant there to unlock them, preparatory to their closing, at a signal from the operator in the gallery. This eliminates the danger of closing a dead machine on the line or other machine by mistake.

This segregating of switchbords and swithhes makes a more expensive constructioh and where the first cost is anitem, or where the plant is small, the switchbords should be concentrated. In hydro-electric plants, where the lines are in general long ones, and this fact precludes the possibility of a large number of them, the operation of the lines will not be necessary more than perhaps once a day, so that the above mentioned precautions need not be taken in their operation.

The following instruments should be located on the main switchboard:- For each generator panel,

three ammeters, three indicating wattmeters, one voltmeter with selector switch for each phase, one integrating wattmeter, and one field ammeter.

The switches and auxiliary apparatus should comprise: An oil switch control for throwing the machine to H.T. bus, generator field switches, and a field rheostat control. The field switches should be equipped with a clip for short-circuiting the generator fields through a resistance when the switch is opened, thus avoiding the introduction of stresses into the windings by the induction of a high potential at that time.

The exciter equipment should consist of an ammeter and voltmeter for each unit, swithes for throwing the exciter to the exciter bus, field rheostats for the voltgge regulation, and the necessary equipment for the operation of the prime mover. If this is a motor there should be an integrating wattmeter to register the power consumed in excitation. Equalizers should also be installed if the exciters are compound wound and designed to operate in parallel.

On the high tension side there should be overload relays on each phase, actuated from series transformers and esigned to open the generator switch at any desired overload and after any desired interval. These should be of the bellows type.

In the station some kind of frequencylimiting device is necessary to trip out the machines should they have a tendency to race beyond control. This may be of the inductive balance type or purely mechanical, and a common practice is to design the instrument so that it will operate at a frequency ten percent above normal. This values seems somewhat low for isolated plants, and fifteen percent would appear to be better.

Governors actuated by an electrical connection with the load ammeters have been suggested in order to eliminate the time necessary for the system to change in speed, but the idea has not as yet been tried, and seems not to find favor with the designers of these plants.

Part II.

Design for Proposed Hydro-Electric Power Generating Station, Malad River, Idaho.

Hydro-Electric Plant,- Malad River, Idaho

Introduction.

In undertaking the actual design of a hydro-electric power plant, it was desired to have as near working conditions as possible. The selection of the location on the Malad River, Idaho was made after data had been secured which gave the exact conditions that existed at this point.

The General Problem.

The source of the power for the proposed plant is from the Malad River - a tributary of the Snake River: the two meeting in the western part of Lincoln county, which is located in the south-central part of the state of Idaho.

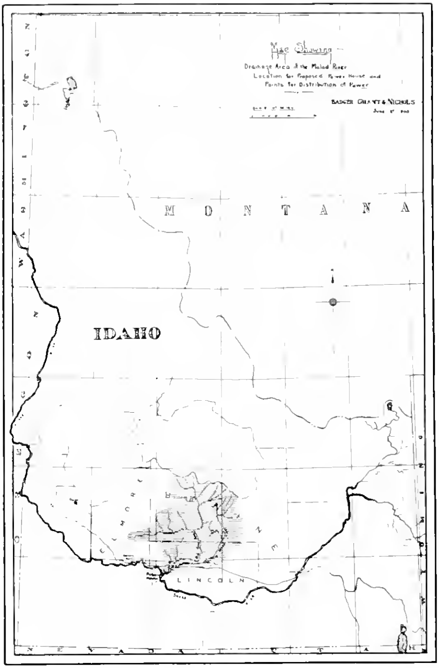
The present market for power from this source is that offered by the city of Boise - for light and power- a hundred miles distant: the town of Glenns Ferry - principally for light - thirty miles distant: and locally,within a radius of from five to ten miles - for irrigation pumping purposes. A possible future market consists in certain rail-

road electrifications that have been proposed in the vicinity.

No continuous record is available on the flow of the Malad River, but from such readings as have been taken of this quantity, it is evident that there is a uniform volume of water in the stream highly sufficient to carry a plant of 4800 kw. - such as is here proposed. This allows for the diversion of small quantities of water for irrigation purposes, these being protected by existing water rights.

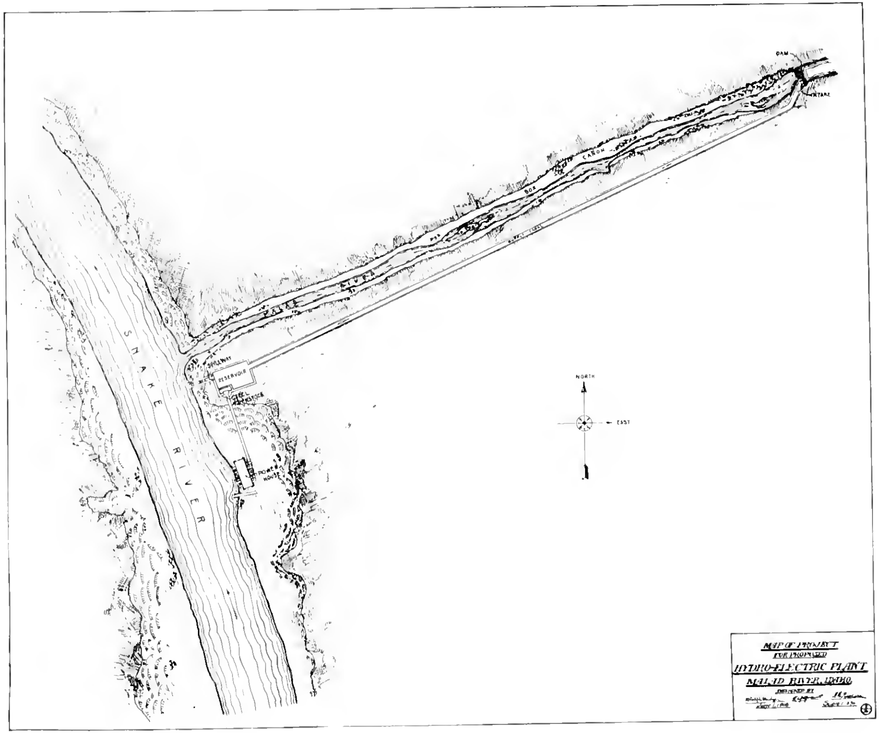
The Water Supply.

The Malad River is supposed to be the outlet for both the Big Wood and the Little Wood Rivers. These latter rise on the southern slopes of the Tetan Mountains which form a water shed extending along the northern boundary of Blaine county, Idaho. From here the rivers flow southward, fed by numerous smaller streams,- a distance of some hundred and fifty miles. At this point they join, disappearing


Map Showing
Drainage Area of the Malad River
Location for Proposed Power House and
Points for Distribution of Power
BADGER GRANT & NICHOLS
MONTANA
IDAHO
ELMORE
LINCOLN
NEVADA
UTAH

from the surface of the earth. Ten miles farther on the Malad River rises - being the accumulated waters of thousands of springs. The theory being that the two rivers - the Big Wood and the Little Wood - after leaving the surface, traverse a subterranean passage which terminates under the springs which form the nucleus of the Malad River. The water of the Malad is a constant in temperature almost throughout the entire year, this being at about 60° Fh. The course of the stream, from the springs that form its source, lies through a box canyon about three miles in length - to the south west, where the Malad empties its waters into the Snake River.

The drainage area of the Big Wood and Little Wood Rivers constitutes what is known as the "Big Camas Prairie", which lies chiefly in Blaine and Lincoln counties. The rainfall over this area is fairly uniform in its distribution. The walls of the box canyon through which the Malad flows are composed of lava and basalt rock. For a short dis-


DAM
INTAKE
BOX
CANON
SNAKE RIVER
SPILLWAY
RESERVOIR
POWER HOUSE
NORTH
EAST
MAP OF PROJECT
FOR PROPOSED
HYDRO-ELECTRIC PLANT
MALAD RIVER, IDAHO

tance its banks arecovered with volcanic dust over which there is a sparse growth of sage brush.

The General Lay-out.

A reference to the "Map of Project",shown in the second illustration, will give an idea of the general lay-out as designed. At a point,a mile and a quarter from its junction with the Snake River, a dam is to be constructed across the Malad. An intake located here leads into an open channel through which the water is conveyed to a reservoir, from which it falls to the power house through a circular steel penstock. A spillway is located at the reservoir - for discharge into the Snake River direct. A controlling gate is located at the head of the penstock.

Power House.

The power house is to be located on the bank of the Snake River. In construction it is to be two stories in height, of concrete throughout. The foundations consist of layers of concrete resting

on bed rock.

Equipment.

Water-wheels, unlike electrical apparatus, are not rated to carry any overload, so that any that is necessary to allow the shutting down of one of the units must be provided by installing wheels of the maximum capacity to be obtained at any time. The capacity of the station being 4800 kw., the installation will therefore be of four 2000 H.P. wheels, thus allowing an overload capacity of the desired amount. After considering the various types of wheels it was decided to adopt the type manufactured by the James Leffel Company. These areof the horizontal type, direct-connected, and are especially designed for the head considered- 185 feet. The efficiency at full load is found to be 86%, at three-fourths load 82%, and at half load 75%. The maximum efficiency is therefore obtained at the output of the apparatus which corresponds to full load on the generators, and any over load will somewhat lower the efficiency.

The dimensions over all are eighteen feet by seven feet. eight inches, the diameter of the intake sixty inches, and of each of the two draft tubes - at the lower end - forty-eight inches, and at the outlet - thirty-two inches. Details of these wheels are shown on Drawing No. VIII.

Due to the peculiar advantages of the ground lay-out it is decided to bring the water into the power house overhead, by means of the large pipes shown in the drawings. These derive their power from the main penstocks, which is eleven feet in diameter at the outer end and narrows down to five feet for the last unit.

The governors used are of the standard type B - Lombard, and are purchased with the turbines. These operate by means of a mechanical connection with the units instead of by means of an electrical connection wi th the ammeters, as has been suggested in the first part of this paper. The estimated loss of time in their operation is approximately one second and is due to the large amount of inertia of the rotating parts. Further loss of time is eliminated

by the installation of a reservoir near the station of sufficient capacity that the water level will never fall appreciably when a sudden demand is made for power. The time taken for the pulse to reach the station from the dam will be the distance divided by the velocity of sound in water.

Choice of generators is largely a matter of personal opinion, since the output of the large manufacturing companies is of a high degree of excellence. Due to the restrictions on the frequency noted above, this figure was taken at twenty-five cycles. The speed is therefore limited to the values given in the first part of this treatment under the head of Electrical Units. The values are, 300, 375, 750, etc. Since direct-connection with the water wheels is desired,the speed which was decided upon was 375 r.p.m. in order to conform in speed with the water wheels selected. This is a standard machine for the capacity wanted - 1200 kw. - so that no trouble was experienced due to too high

a peripheral speed.

The transmission distance (maximum) is one hundred miles, so that there will be the necessity of stepping up the voltage for transmission, and the pressure of the machine is immaterial within wide limits. This figure was taken at 11,000 volts for the following reasons: Part of the power is to be transmitted a distance of thirty miles and it is desireable not to retransform this power from the extremely high voltage for the longer transmission. The machines are therefore connected directly to a "low tension" bus, at a pressure of 11,000 volts and the power for the shorter transmission istaken from this bus, while the transformers are fed from the 11,000 volt bus and transform the pressure from that to the value required for the longer distance.

Since the rough approximation for the transmission voltage demands a pressure of 100,000 volts,

and this is at present beyond the capacity of the insulators available, the voltage decided upon was 66,000, giving a value of volts per mile as 660, which is in accord with modern practice.

As was noted above, it is necessary to have two independent sources of excitation, and this is accomplished by means of the motor-and water-wheel driven units shown in the drawings. Greater dependence will be placed on the water-wheel-driven apparatus, so that two of them are installed and the motor-driven unit is to be used in emergencies, and to run in parallel with the others during the peak load or at times when a shut down would be most disastrous. Each of the exciter units are of 75 kw. capacity and the motors and water-wheels of 100 HP each. The power for the motor-driven exciter will be derived from a transformer fed from the "low tension" bus, the e.m.f. being stepped down from 11000 to 220 volts. The motor is of the induction type and is started by means of

the special starting taps shown diagrammatically in the wiring diagram. This dispenses with the necessity for auto-transformers, and the more expensive construction entailed. It will be necessary only to bring out two additional leads from the secondary of the transformer, and since this may be located at no great distance from the exciter, the expense will be small compared with that incident to the use of an auto-transformer.

By thus dividing the units there is no danger that the excitation of the fields will be lost at any time except under the most extraordinary conditions. These precautions are necessary due to the fact that the exciter system is the weakest part of the plant and the greatest care must be taken in its design if continuity of operation is expected.

The conditions influencing the use of single or three phase transformers were noted above. In this case it was decided to install single phase units due to the fact that the country is rough

and the distance to which they must be transported is rather large. It also makes necessary the installation of a comparatively cheap unit only, this being placed somewhere on the floor of the transformer room and connected in as desired by means of flexible leads.

The capacity of the transformers will be ten percent greater than that of the generators to conform with common practice, so that each unit must be rated at 440 kw. These are to be connected up delta on both sides. This is also an additional safeguard, since in this case if one of them becomes burned out, the other set can then carry 58% of the load with the same heating by operating on a V-connection, and, the continuity of the service need not be interrupted during the time necessary for the installation of the spare unit.

On account of the character of the load the operation of the lines will not be necessary more than once or twice a day and therefore attendance

of an operator on the switches will not be necessary. These switches should be located, however, in another room to protect them from the dampness, and to insure their proximity to the high tension buses. For this reason they are to be located up-stairs where they can be readily reached from the lower floor by the two stairways. The high tension buses are also located here so thata minimum amount of copper is required. The two buses run parallel throughout their length, asshown, and this makes it possible to extend the plant at any time by merely tearing out the end walls and installing a new unit. The buses can then be extended also and the station will then be symmetrical as before.

The drawings showing the arrangement of the above specified apparatus and machinery are reproduced in the following pages.

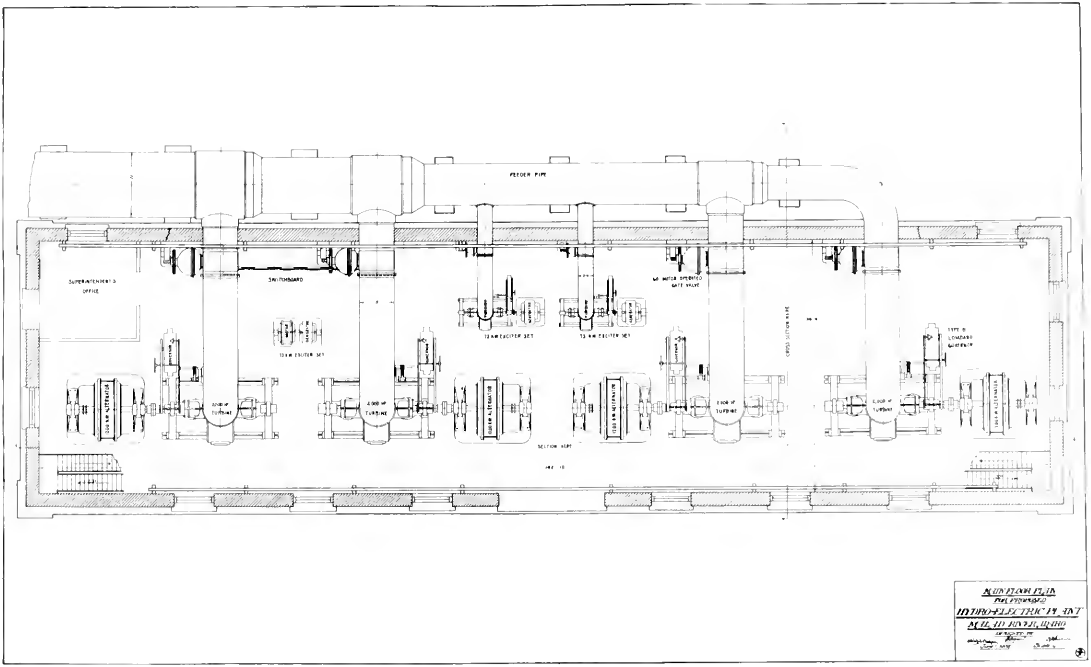
D R A W I N G S

for proposed

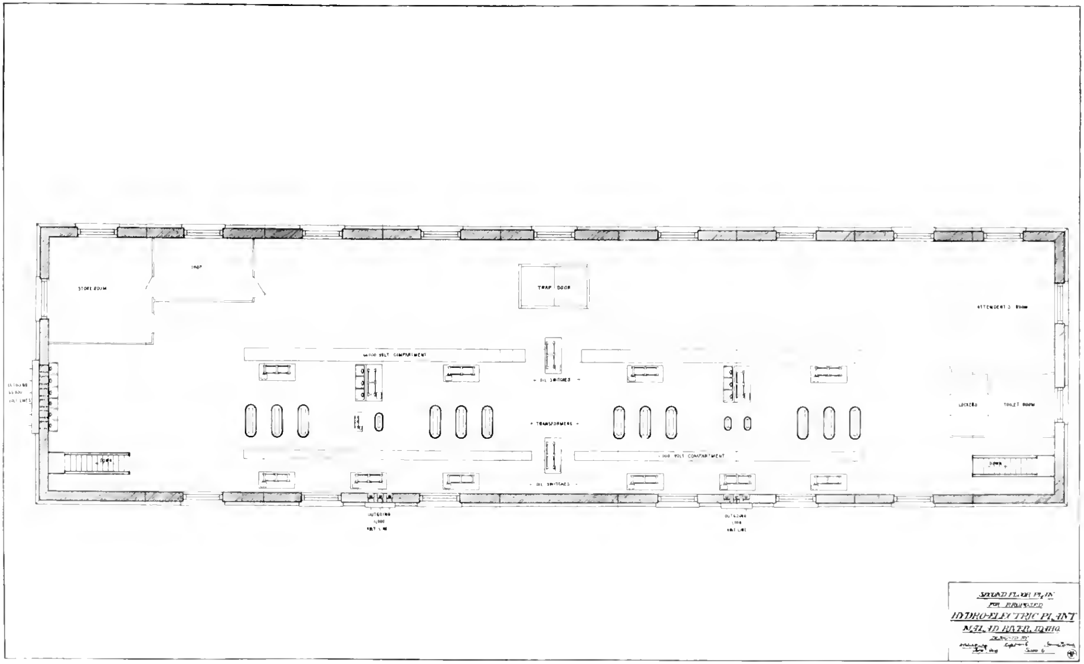
HYDRO-ELECTRIC POWER PLANT

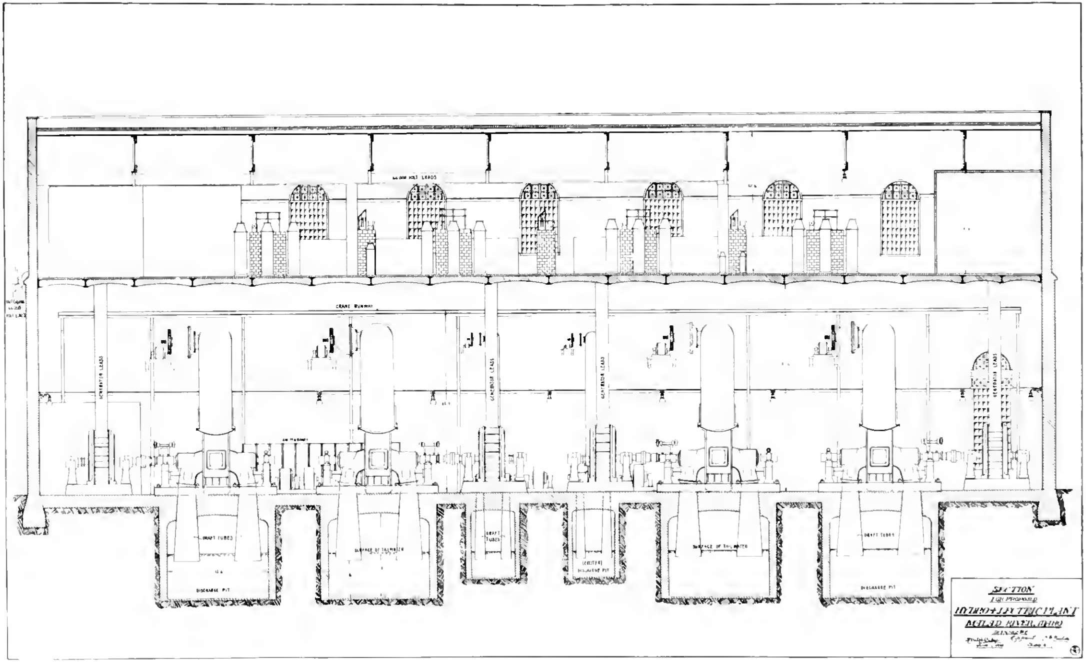
Malad River,

Idaho.

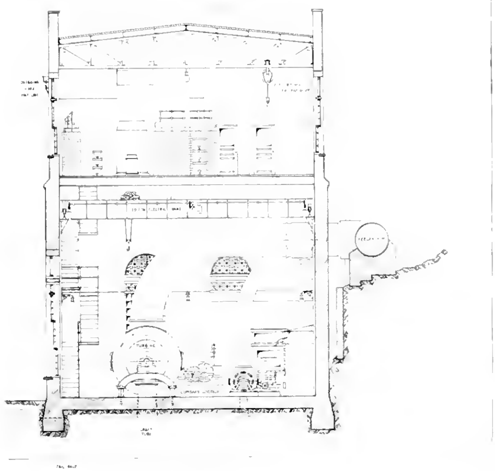


HYDRO-ELECTRIC PLANT
FEEDER PIPE
SUPERINTENDENT'S OFFICE
SWITCHBOARD
13 KW EXCITER SET
60 MOTOR OPERATED GATE VALVE
CROSS SECTION HERE
TYPE D LOMBARD GOVERNOR
1200 KW ALTERNATOR
2,000 HP TURBINE
SECTION HERE

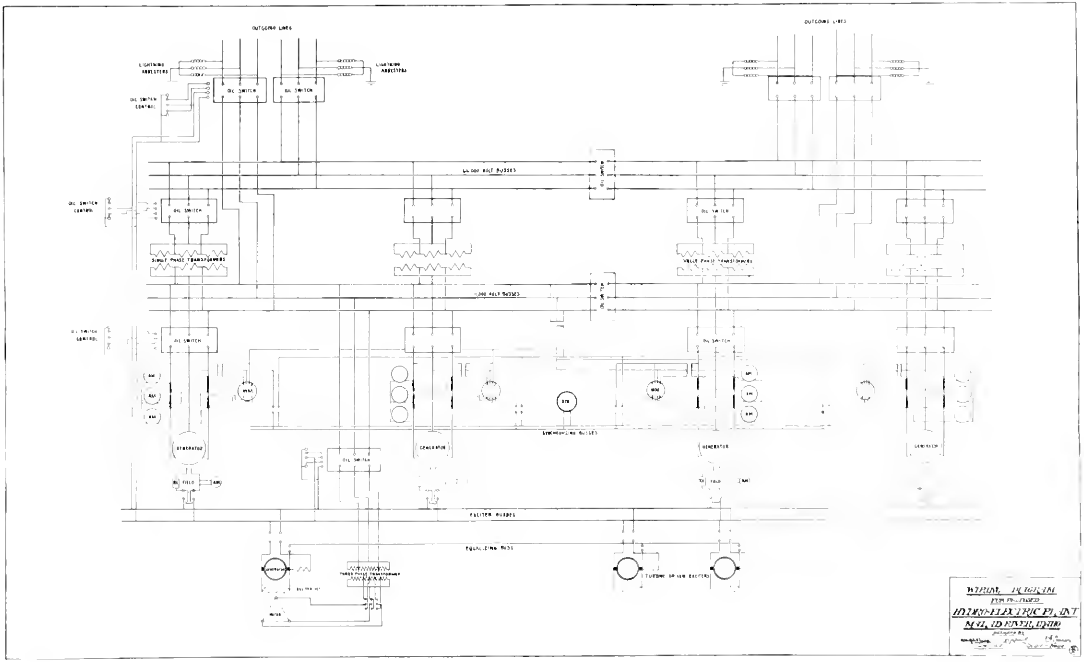

STORE ROOM
TRAP
TRAP DOOR
ATTENDENT'S ROOM
VOLT COMPARTMENT
OIL SWITCHES
TRANSFORMERS
VOLT COMPARTMENT
OIL SWITCHES
LOCKERS
TOILET ROOM
DOWN
DOWN
OUTGOING
OUTGOING
HYDRO-ELECTRIC PLANT

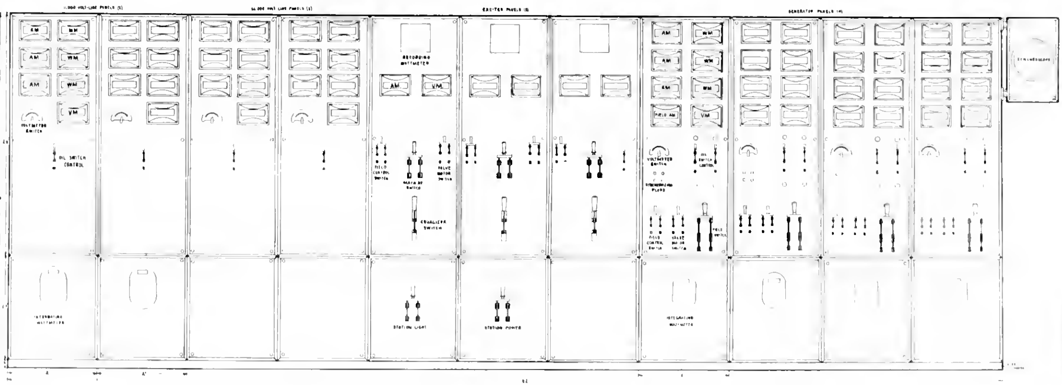


SECTION
FOR PROPOSED
HYDRO-ELECTRIC PLANT
66,000 VOLT LEADS
CRANE RUNWAY
GENERATOR LEADS
DRAFT TUBES
SURFACE OF TAILWATER
DISCHARGE PIT



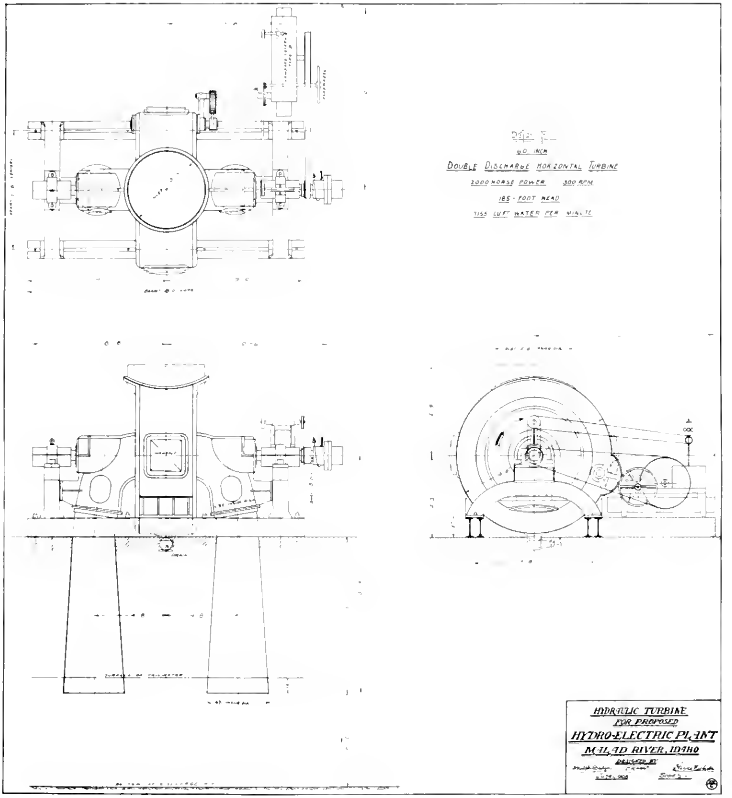
CROSS SECTION
FOR PROPOSED
HYDRO-ELECTRIC PLANT
MALAD RIVER, IDAHO
DESIGNED BY


OUTGOING LINES
LIGHTNING ARRESTERS
OIL SWITCH
OIL SWITCH CONTROL
66,000 VOLT BUSSES
SINGLE PHASE TRANSFORMERS
GENERATOR
FIELD
SYNCHRONIZING BUSSES
EXCITER BUSSES
EQUALIZING BUSS
THREE PHASE TRANSFORMER
TURBINE DRIVEN EXCITERS
MOTOR
WIRING DIAGRAM
FOR PROPOSED
HYDRO-ELECTRIC PLANT
MALAD RIVER, IDAHO
DESIGNED BY



SWITCHBOARD

HYDRO-ELECTRIC PLANT


60 INCH
DOUBLE DISCHARGE HORIZONTAL TURBINE
2000 HORSE POWER 300 RPM
185 - FOOT HEAD
7155 CU FT WATER PER MINUTE
HYDRAULIC TURBINE
FOR PROPOSED
HYDRO-ELECTRIC PLANT
MALAD RIVER, IDAHO

Transmission of Power:—There are to be two 66000 volt three phase, twenty-five cycle transmission lines from the plant to Boise City and to Glenn's Ferry, Idaho. In addition there are two 11000 volt lines to supply power for public purposes in the vicinity of the plant. The calculations for the 66000 volt lines follow:

Boise City line, 100 miles long, 3200 kw. to be transmitted, transmission voltage, 66000

Line loss	256 kw.
Res. per wire	109 ohms,
Size of wire	# 3 Band S.
Distance between wires	6'—6"
Inductance per wire	.21 henrys
Capacity to neutral	1.36×10^{-8} f/mile
Natural frequency	470 cycles
Charging current	8.2 amp.
Ind. reactance	33 ohms
Cond. reactance	4670 "
Reg. no load	.374%

Reg. full load	3.1 %
Reg. 85% power factor	4.3 %
Wt. copper	252,642 #
Spacing of poles	45/mile
Number of poles	4,500

Glenn's Ferry Line.

30 miles long, 800kw.

Transmission voltage	66,000
Line loss	1.8 %
Resistance per wire	97.5 ohms
Size of wire	# 8
Distance between wires	6' - 8"
Inductance per wire	.068 henrys
Capacity to neutral	$.375 \times 10^{-8}$ f/mile
Natural frequency	1,570
Charging current	2.25 amperes
Ind. reactance	10.6 ohms
Cond. reactance	17,000 ohms
Reg. full load	.05 %
Reg. 85% power factor	.08 %
Number of poles	1,350

A P P E N D I X.

Hydro-Electric Power Station Design.

B I B L I O G R A P H Y.

Hydro-Electric Power Plants; Beardsley.

Transmission of Water Power; Adams.

Standard Handbook for Electrical Engineers; McGraw

Water Supply Papers; U. S. Geological Survey.

Notes and Designs on Hydro-Electric Power Stations,

American Institute E. E., 25:163, Apr.06

Location of Electric Water Power Stations,

Cassiers, 25: 496.

Electricity from Water Power,

Elec. Eng., 34: 294

Modern Power Plant Design and Economics,

Eng. Mag., 28: 689, 812.

" " 30: 71, 182.

Use of Pacific Coast Water Powers in Electric Operation of Railroads,

Jour. Elec., 15: 115.

Sixth Biennial Report, 1905--6

State Eng. Idaho.

Water Power of the Rock River: Mead.

P R I C E S and C O S T I T E M S.
(Malad River Project)

Hydraulic Turbine Units-

Including draft-tubes and type "B" Lombard Governor. Gross weight about 75,00 pounds. F.O.B. cars at factory, each -

$ 7,800.00

Steel Penstock -

Circular in form: of riveted steel plates, with necessary saddles and stiffeners. Per lineal foot (about) -

$ 45.00

Wooden stave pipe at about half this figure.

Nearest railroad connection - at Bliss, Idaho (three and one-half miles) : Oregon Short Line.

Freight rate to this point, from Chicago, on eledtrical machinery about 1 1/2 cents per pound. The rate on structural steel from Pueblo to Bliss,- about 75 cents a hundred.

Cement : about $3.25 a bbl., f.o.b. Bliss.

Sand, rock and gravel to be had on the work.

Suitable poles for the transmission (thirty-five to forty feet long) can be had on the work for about $5.00 per pole.

Market for power -

Transmitted and distributed to Boise - 100 miles,- 2-1/2 cents a kw. hour.

To Glenns Ferry - 30 miles,- 5 cents a kw. hour.

For pumping purposes in vicinity of plant,- 1-1/2 cents a kw. hour.

Transmission Lines.

To Boise (100 miles) -

Cost of copper	$	37,296.00
" " poles		18,900.00
" " cross arms		3,150.00
" " insulators		23,625.00
" " pins		7,200.00
Total	$	90,171.00

To Glenns Ferry (30 miles) -

Cost of copper	$	3,566.00
" " poles		5,670.00
" " cross arms		945.00
" " insulators		7,088.00
" " pins		2,160.00
Total	$	19,429.00