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Transformer Losses Evaluation Factors for the Generator Transformer of Proposed Kalabagh Hydro Power Station A. Case Study

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TRANSFORMER LOSSES EVALUATION FACTORS FOR THE GENERATOR TRANSFORMER OF PROPOSED KALABAGH HYDROPOWER STATION: A CASE STUDY

BY

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1. ABSTRACT

Initial price may be the only criterion for consideration while purchasing a few 25 kVA distribution transformers, however, when huge transformers of many MVA capacities are to be procured, no-load losses and load losses, being substantial, are always taken into account.

The overall efficiency of commercial transformers is usually about 99%; thus the total loss of 1% is comprising of no-load losses and load losses. For calculation purposes the evaluation factors for no-load losses and load losses are always provided by the purchaser and are considerably different for different power systems. By this information the manufacturer can modify his design of the transformer to make his offer more competitive.

In this paper a refined method of determining such evaluation factors is described in detail. For clarity, the case of the generator transformer of Kalabagh power station is discussed in detail.

2. INTRODUCTION

While procuring a few small distribution transformers of 25,50 and 100 kVA capacities, the initial price may be the only deciding factor as the losses are negligible (Appendix A); however, in the case of huge transformers, in addition to the initial price, cost of power losses as well as cost of providing of power for these losses and energy consumed is always taken into consideration (Appendix B).

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The efficiency of power transformers of large capacities is as high as 99% to 99.5% owing to perfection of transformers technology (1). The 3-phase self-oil-cooled and water-cooled transformers have the lowest total loss and the highest core loss when compared to transformers cooled in other ways. On the other hand forced-oil-cooled transformers have the highest total loss and the lowest core loss, because due to this method of cooling the capacity is increased. It is quite clear from here that the manufacturer can adjust his no-load losses and load-losses by incorporating some changes in the design; however, costs of no-load loss and load loss evaluation factors are different for different power systems and are always provided by the purchaser; the manufacturers of transformers always seek the losses evaluation factors from the purchaser so that they can modify their design etc., to make their offers more competitive.

3. METHODOLOGY AND CALCULATIONS

Different methods for determining the losses evaluation factors have been in use during the last 50 years. A reference (1) states that about 25 years back the following method was employed:

"Calculate the energy loss and account for the value of the lost energy at the rate of $ 0.0042 to $ 0.0084 per kWh for the life of the transformer. The expected loss and the cost of the energy should be calculated at various load factors and system conditions for accurate evaluation. The cost per kWh loss will depend on the type of power station and its economics. To be accurate, it is not enough to evaluate the loss of energy at the rate per kWh at the power station. The consumer must pay for the I^2Rt loss as well as for the plant installed to supply it. This should be considered in accurate evaluation and comparison for the total economics".

In recent times the following two formulas have been used by many utilities for determining the evaluation factors (5):

(a) No-load loss factor = F_{nl} =

(Capital cost/kW x capital recovery factor)

+ (8760 x Energy cost/kWh x outage weighting factor)

(b) Load Loss factor = F_{11} =
(Capital cost/kW x capital recovery factor x capital weighting factor)
+ (8760 x Load loss factor x loss weighting factor x Energy cost/kWh).

The components of the formulae are described in detail in the following lines:-

3.1 Energy Cost

An ideal power transformer should have no losses and consequently it should not consume any electric energy.

However, in practice an ideal transformer does not exist. So whenever a power transformer is connected to the system, it will consume some energy like any other load.
In the existing tariff there are different rates per kWh for different consumer categories (i.e. residential, commercial, industrial etc.) A reference (4) has described in detail the techniques and philosophy employed in the design of tariff, however, for our purpose a simple approach is adhered to: find out the WAPDA's cost of 1 kWh of energy and then determine as to how much is the cost of the energy loss for the transformer.

According to WAPDA Annual Report of 1982/83, the total energy units sold were 11587 x 10^6 kWh while the total expenses, as shown at page 158 of the said report, are as following:-

TABLE 1

TOTAL COST DETAIL

Item Description	Cost in Million Ruppees
- Generation	1870.93
- Transmission	226.88
- Distribution and Commercial	1119.79
- Depreciation	818.56
- Headquarters	9.72
Total	4045.88

In addition, there is interest on loans which is also to be included in the expenses; thus Rs. 1190.61 millions are added in the expenses. At the same time it is shown in the report that WAPDA earned a net profit of Rs. 2214.66 millions. Hence the net expenses are (4045.88 + 1190.61 - 2214.69) = Rs. 3021.80 millions.

From here it is gathered that WAPDA's real cost for each kWh sold is $(3021.81 \times 10^6) \div (11587 \times 10^6)$, which comes out to be Rs.0.2608.

Now this is the estimated cost for the year 1982/83; however, the tender assessment will be performed in mid 1989/90 as per the current schedule. During this period, the costs will increase due to inflation but decrease due to improvements in efficiency. It is guessed that the net effect will be a 5 percent per annum increase.

Thus energy cost per kWh = $(1.05)^7 \times 0.2608$ = Rs.0.3670

2 Capacity Cost

If we assume that our system is 100% loaded then for providing power to cater for the losses of a generator transformer, additional generating unit will have to be installed. This is known as capacity cost.

In the above mentioned WAPDA's report, estimated capital costs quoted in 1982/83, for some power stations are as shown below in Table.2.

TABLE 2

ESTIMATED CAPITAL COSTS OF POWER STATIONS

Project	Capacity MW	Cost Rs.x 10^6	Specific Cost Rs./kW
Tarbela 9 and 10	350	1830	5,229
Guddu Phase III	210	2100	10,000
Guddu Gas Turbine	300	4459	14,863
Kot Addu Gas Turbine.	400	2600	6,500
Jamshoro Coal/Steam	300	6395	21,317

As the power required to supply the Kalabagh transformer losses adds to the peak demand of the system (a logic which we have said above), the capital cost for the additional generating plant is taken as that of the peak lopping gas turbine projects. Guddu Gas Turbine Project is taken as a typical with a specific cost of Rs. 14,863/kW. Allowing for inflation at 5% per annum the specific cost of a similar project in 1989/90 i.e. after 7 years, will be Rs. 20913.7/kW.

3.3 Discount Rate and Life

Based on previous experience, the Discount rate is taken as 10% per annum and the life of the transformers as 25 years giving a capital recovery factor of 0.1102 and a present worth factor of 9.077.

3.4 Load, Load Loss Factors and Loss Weighting Factors

The ratio of average demand and installed capacity is called plant capacity factor. Some studies were carried out for Kalabagh power station and according to a curve shown in Figure 1, the plant capacity factor is 36% for a 12x300 MW station (i.e. in the station there will be 12 units each of 300 MW rating). The rating of the generator transformers is 15% greater than the nominal 300 MW unit rating so that the transformer's capacity factor, as per the above definition, is $36 \div 1.15 = 31.3\%$. The load factor will also be 31.3% because the transformer will be operated for a short period in each year at full load when the reservoir level is at its highest. If the river flow as well as outgoing water for canals at Kalabagh is considered for all the 12 months of the year, it is seen that there will be only a few months when the units are running at full rating and for long periods the units will be running at low output; thus the shape of the load curve will be peaky. It is assumed, based on the previous experience of similar hydrostations, that each will be running for 80% of each year which gives a load factor for the running period of $31.3 \div 0.8 = 39.125\%$. As already stated the load curve will be peaky and according to Berry's formula Load Loss Factor (LLF) will be:

$$LLF = 0.2\ (LF) + 0.8\ (LF)^2$$
$$= 0.2\ (0.391) + 0.8\ (0.391)^2$$
$$= 0.2005$$
$$\simeq 0.201$$

To allow for the periods when the units are not operating, the LLF will be decreased by a factor of 0.8:

Thus corrected value of LLF = 0.8 x 0.201
= 0.161

The corrected LLF value is assumed to be an average value. However, for dry years and wet years the value of LLF will be different. Attached Figures 2,3 and 4 give the output for dry, average and wet years and the annual energy is 9109, 11026 and 12391 GWh respectively. This clearly means that for the wet year there will be an increase of 12.4% of energy from the average year and for the dry year there will be a decrease of 17.4% of the energy from the average year. This gives a load weighting factor (LWF) for variation in annual output.

$$LWF = \frac{1}{3}\ [\ (1-0.174)^2 + (1+0.124)^2 + 1\ ]$$
$$= 0.982$$

This value of LWF (i.e. 0.982) is used in our further calculations.

3.5 Capital Weighting Factors (CWF)

In our country, the dams are not merely for power generation. In fact irrigation is the major task of such dams and quite often commands as to how much power can be generated. Another case is that the period of the highest reservoir level when the generator transformers can be loaded to their full rating does not necessarily coincide with the system peak. In this back-ground it is assumed that maximum contribution to the system peak demand due to the generator transformer load losses will not exceed the losses at the nominal unit rating. This gives a capital weighting factor (CWF) as follows:

$$CWF = \left(\frac{1}{1.15}\right)^2 = 0.756$$

3.6 Outage Weighting Factor (OWF)

When the transformer is not energised, naturally no energy is drawn from the system to supply the no load losses.

Based on the previous experience of generator transformers in other similar projects, it is assumed that the generator transformer will be operating for 80% of the time. Regarding the remaining 20% of the time, for some portion of the time it will be out for maintenance. It is also possible that at times the transformer is energised but it is not in use.

From the above discussion we note that the value of OWF for generator transformer is 0.80.

3.7 CALCULATED VALUES OF LOSS EVALUATION FACTORS

The values of the various items described in the foregoing are put in formulae (a) and (b) to determine the losses evaluation factors.

- No-load Loss Evaluation Factor:

F_{nl} = (Capital cost/kW x capital recovery factor)
+ (8760 x Energy cost/kWh X OWF)

- Here capital cost/kW = Rs. 20913.7
- Capital recovery factor = 0.1102
- Energy cost/kWh = Rs.0.3670
- Outage Weighting Factor = 0.8
- Thus F_{nl} = (20913.7 x 0.1102) + (8760 x 0.3670 x 0.8)
= Rs. 4877 per kW.

The figure is rounded off to give F_{nl} = Rs. 4900/kW

- Load Loss Evaluation Factor:

F_{ll} = (Capital cost/kW x capital recovery factor CWF)

+ (8760 x LLF x LWF x Energy cost/kWh)

- Capital Weighting factor = CWF = 0.756
- Modified value of load loss factor = 0.161
- Load Weighting factor = LWF = 0.982.

Thus F_{ll} = (20913.7 x 0.1102 x 0.756)

+ (8760 x.161 x 0.982 x 0.3670)

= Rs. 2251 per kW

The figure is rounded off to give F_{ll} = Rs. 2300/kW.

4. CONCLUSION

In this paper a refined method of determining losses evaluation factors for the generator transformer of a large hydropower station is described in considerable detail. The same step-by-step procedure can be applied to find out the factors for an interbus transformer or a station transformer.

These factors are quite important for the manufacturers of large transformers because these enable them to modify their design to make their offer more competitive. In fact in the tender enquiry such factors are always stated.

5. REFERENCES

1. "Elements of Electrical Power Station Design", ed 1966, Prof. M.V.Deshpande, pp-268 Pittman & Sons, London.

2. WAPDA Annual Report 1982-83.

3. "Project Planning Report, Vol.8", December 1983, Kalabagh Consultants, Lahore.

4. "Power Station Engineering and Economy", ed.1960, G.A. Skrotzki, pp-641 to 714, McGraw-Hill Book Co, New York.

5. "Project Design Report on North Power Station, Cyprus", May 1980, Preece, Cardew and Rider , London.

APPENDIX A

NO-LOAD AND LOAD LOSSES FOR T'.PICAL 17.5 kV/400-231V DISTRIBUTION TRANSFORMERS

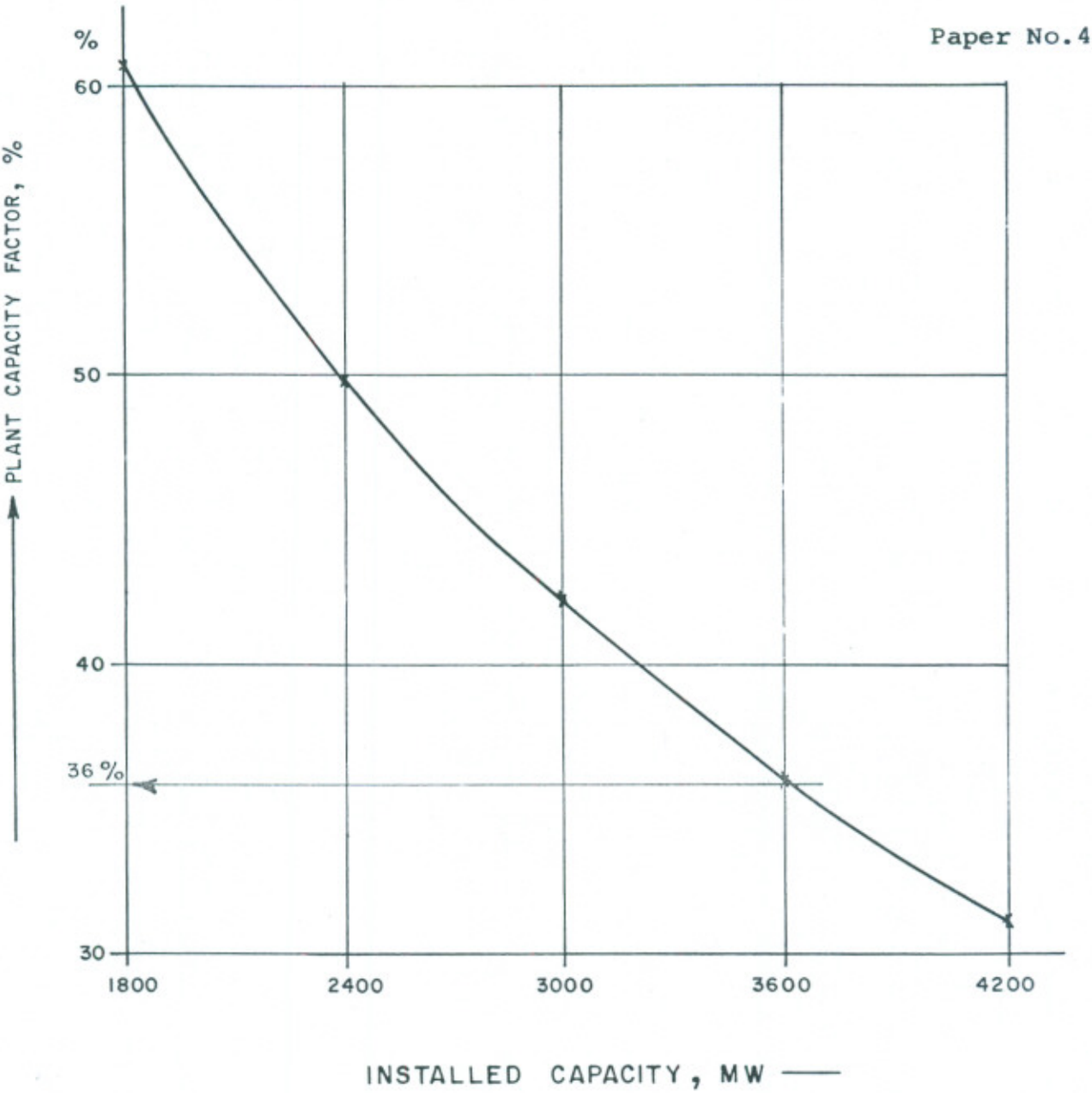
kVA Rating	No-Load Loss (W a t t s)	On-Load Loss (W a t t s)
50	190	1100
80	270	1500
100	320	1750
125	390	2050
160	460	2350
200	650	3250
250	775	3800
315	930	4600
400	1100	5450
500	1300	6500
630	1550	8150
800	1800	10,000
1000	2150	13,000

Source: Messers ACEC (Belgium)Pamphlet No.FCA200-15.56

APPENDIX B

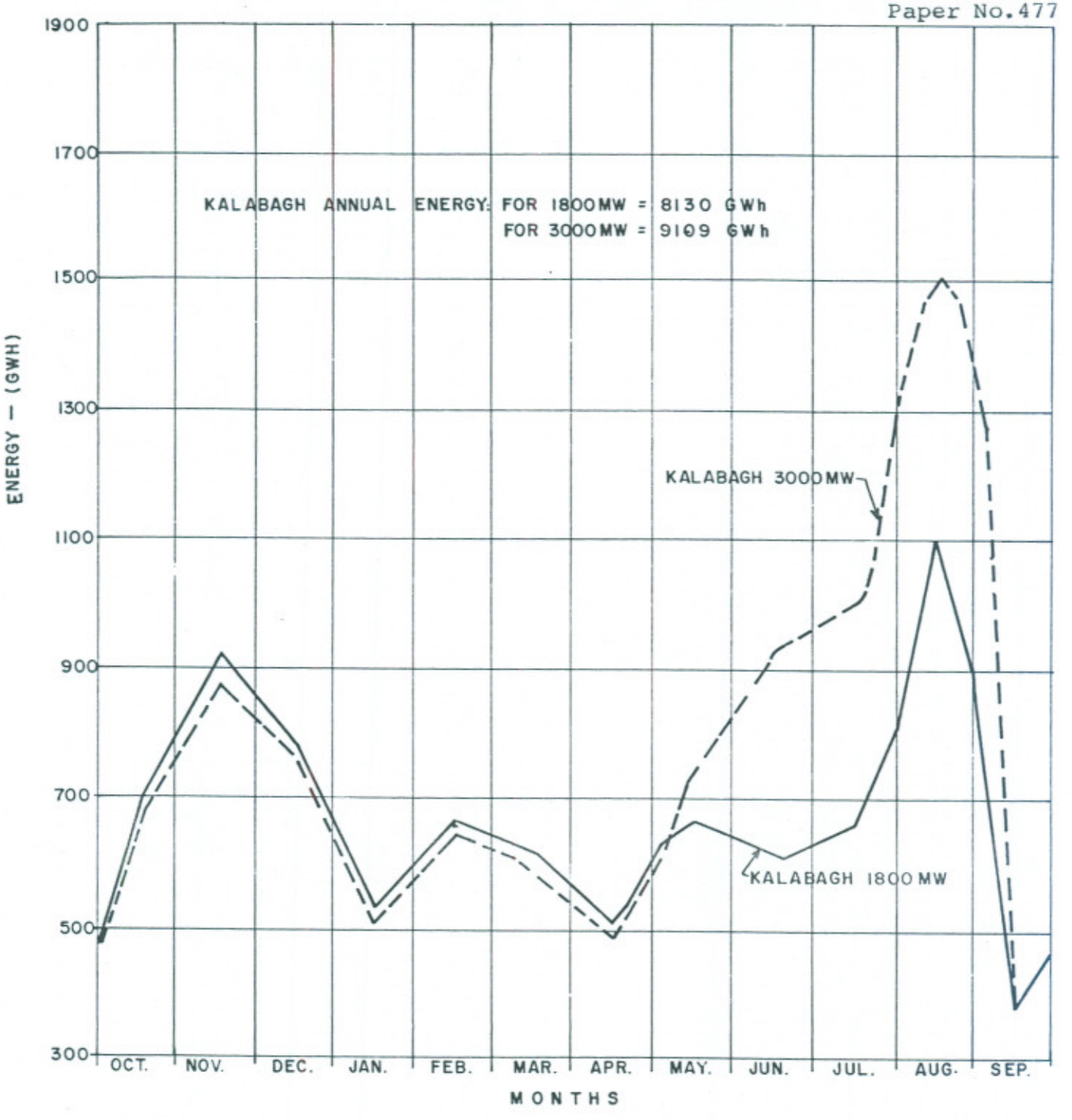
TYPICAL IRON LOSSES AND COPPER LOSSES FOR SOME BIG POWER TRANSFORMERS

Item Description	Iron Losses (k W)	Copper Losses (k W)
- Generator Transformer 500 kV, 363 MVA	215	1100
- Generator Transformer 220 kV, 406 MVA	190	1250
- Auto Transformer, 500/220 kV, 450 MVA	190	960
- Station Transformer 220/11kV, 15 MVA	40	80



KALABAGH PLANT CAPCITY UTILIZATION FACTOR

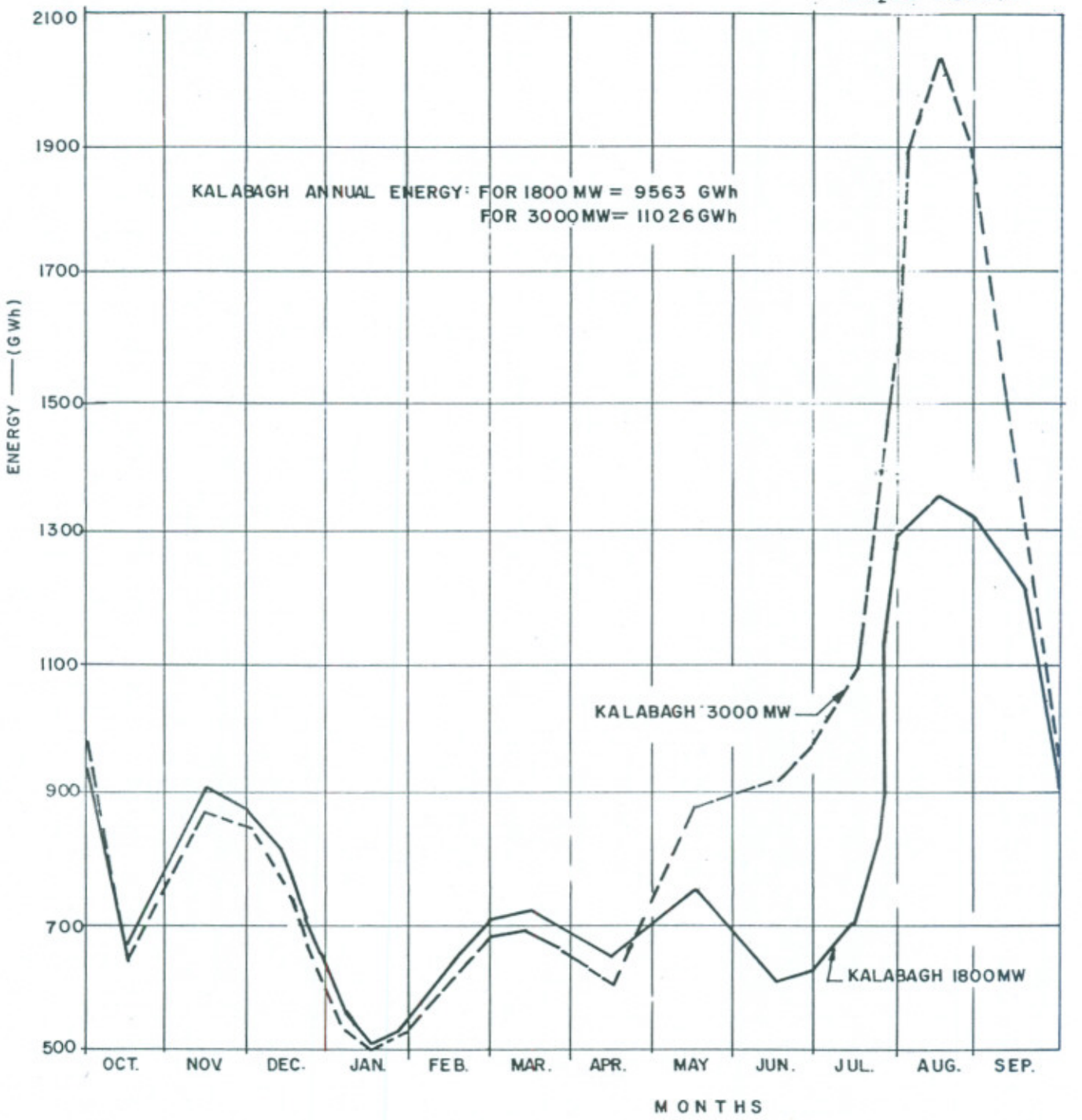
FIGURE 1



KALABAGH MONTHLY ENERGY
DRY YEAR (1970 - 71)

MID LEVEL SLUICING - 925 ft. RRL

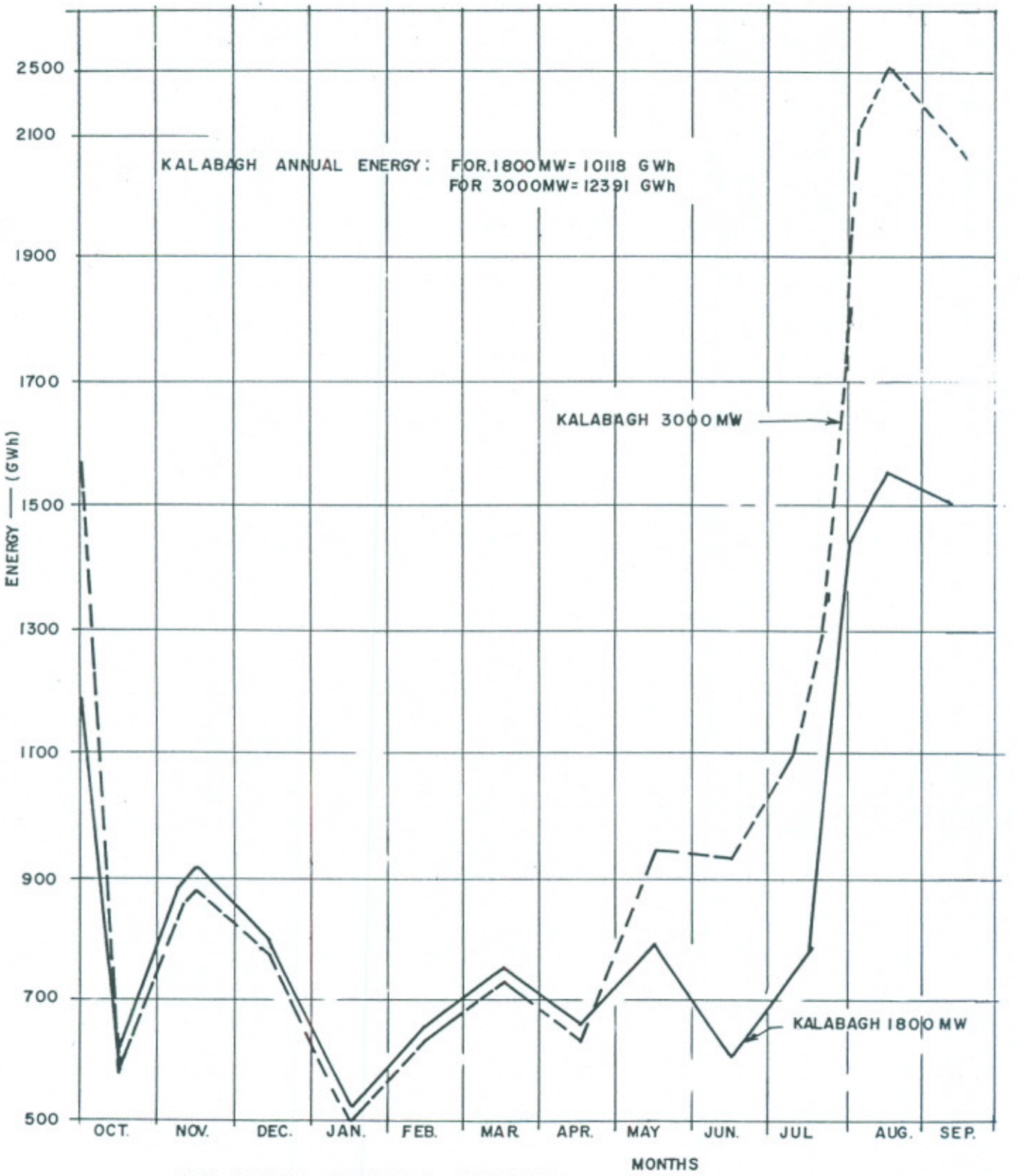
FIGURE 2



KALABAGH MONTHLY ENERGY
(AVERAGE YEAR)

MID LEVEL SLUICING – 925ft. RRL

FIGURE – 3



KALABAGH MONTHLY ENERGY
WET YEAR (1972 — 73)
MID LEVEL SLUICING- 925 ft. RRL

FIGURE - 4