TUTA/IOE/PCU

Journal of the Institute of Engineering, Vol. 10, No. 1, pp. 104–120

Fax: 977-1-5525830

Performance Evaluation of Runoff River Type Hydropower Plants Operating in Nepal: A Case Study of Nepal Electricity Authority

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Abstract: Every power plant undergoes repair and maintenance which reduces the performance of the power plants as their condition undergoes periodic deterioration. To rectify the situation of aging and deterioration, timely evaluation of existing power plants is a must. Such that the evaluation will enable the decision maker to make decision regarding the present operation and maintenance practice: the need for modification of the practice or need to undergo rehabilitation in order to operate existing plants in a more efficient and effective way. Performance evaluation of a hydropower plant is performed .on the basis of various performance indicators.

Keywords: Hydropower Plant

Introduction

Hydropower has been identified as the key source of commercial energy for electricity generation which can propel the growth of the nation. Nepal's theoretical hydropower potential has been estimated at about 83,000 MW and its technically and economically feasible potential of about 45,000 MW and 42,000 MW respectively [12].

The Integrated Nepal Power System (INPS) consist of hydropower as the primary source of energy with small contributors like diesel and solar. In the present context of Nepal the demand of electricity has exceeded the amount of electricity that can be supplied by NEA, resulting in power interruption throughout the country. To tackle the shortage of energy, NEA is importing electricity from India, producing electricity from fossil fuel for short term preventive measures. Even after implementation of preventive measures the peak demand (1,026 MW) has not been met [8]).

To solve the energy crisis problem, Government of Nepal has declared a state of emergency and drafted ten years and twenty years hydropower development program along with suitable policy for fast tracking the development of hydropower. It has been forecasted that until 2030 A.D. a total of 20,354 MW will be added to the INPS excluding the projects such as Pancheswor, Chisapani and Saptakoshi Multipurpose Project; at the same time the forecasted demand will reach 11480 MW [7].

During the course of operation, component life of various parts such as civil, mechanical, electrical are subjected to various wear and tear thus requiring repair and maintenance at regular interval. In the context of aging hydropower plants, a stage will occur when the option of Renovation, Modernization and Upgrading (RM&U) seems more economically feasible rather continuing the regular Operation and Maintenance (O&M).

Renovation, modernization and upgrading (RM&U) of old power stations is often less costly than developing a new power plant, often has relatively smaller environment and social impacts, and requires less time for implementation. Capacity additions through RM&U of old power stations can therefore be attractive. Replacement or repair of selective hydro powerhouse components like turbine runners, generator windings, excitation systems, governors, control panels or trash cleaning devices can reduce costs and save time. It can also lead to increased efficiency, peak power and energy availability of the plant [10].

Continuous effort should be done for the performance assessment of the condition and performance of the plants on the basis of various performance indicators in order to find out the potential areas for improvement. The assessment enables to analyze the entire fleet of plants owned by an enterprise such that the plant that needs more focus can be identified and timely decision can be made accordingly. If the improvements that can be made are economically and financially justified then decision must be made accordingly.

In this paper focus on performance evaluation of runoff river type hydropower plants owned by NEA having Francis turbine as its prime mover on the basis of performance evaluation.

Performance measurement refers to the use of a multi-dimensional set of performance measures. The set of measures is multi-dimensional as it includes both financial and non-financial measures, it includes both internal and external measures of performance and it often includes both measures which quantify what has been achieved as well as measures which are used to help predict the future sustainability.

Research Methodology

A screening process was implemented and a population of seven hydropower plants were listed for analysis purpose.

Questionnaire were prepared and distributed to the hydropower plant personnel, managers, consultants and academicians for finding out the criteria that would act as key Performance Indicators of a hydropower plant for analysis purpose. From the questionnaire survey, a list of criteria were prepared and managed in a hierarchical manner.

This study is based on both qualitative and quantitative information. The data is based on both primary and secondary data field. Primary data was taken from field visit to selected hydro power plants. Secondary data were collected from other various sources. Analysis was carried out on the plant as a whole from its intake section to generator section. Empirical data were obtained from plant records for a period between 2066/67 and 2069/70, prepared by the power plant and maintained by Operation and Maintenance Department of the plant.

Data Collection

Primary Data Collection

The primary data were collected by site visit to the chosen hydropower plants. At the site the form of condition assessment was filled by observing all the necessary parts with the help of concerned personnel mainly engineer and supervisor. After conducting the survey discussions were held regarding the brief overview of the operation of the plant and conditions of equipment along with their maintenance. The data for performance measurement was also compiled via various equipments located at the power plants. Data stored on memory of control room computers were also collected. The hourly analogue data maintained by Shift In charge on daily log sheets were taken and upgraded to digital data.

Collection of Secondary Data

Secondary data was collected from different offices of Nepal Electricity Authority (NEA) such as Load Dispatch Centre (LDC) and Office of Generation, Operation and Maintenance. Various related publications, reports, literatures, studies, etc. have been collected from the different related offices. Beside these, related information was also collected from related web sites.

Performance Analysis of Hydropower Plant

Performance analysis is done on the basis of power generation in MWh/GWh achieved by the hydropower plants, availability, staffing level, economic efficiency etc. as mentioned in the section Plant Performance Indices.

Condition Assessment of Hydropower Plant

Condition assessment is done during the site visit by observation, interviews, and historical data collected. The taxonomy devised in the HAP is followed for easy identification of parts and standardization. The guidelines and checklist is also followed. The scoring guide is modified as per discussion with the experts of the relative fields currently working in Nepal Electricity Authority (NEA).

The following table shows the power plants that NEA is currently operating or has given in the form of lease to private sector.

Table 1: List of Grid Connected hydropower plants owned by NEA

S.N.	Name of the Powerplant	Capacity in kW		S.N.	Name of the Powerplant	Capacity in kW
1	Middle Marshyangdi	70,000		17	Tinau (Butwal)	1024
2	Kaligandaki A	144000		18	Sundarijal	640
3	Marshyangdi	69000		19	Pharping	500
4	Kulekhani No. 1	60000		20	Jomsom	240
5	Kulekhani No. 2	32000		21	Baglung	200
6	Trisuli	24000		22	Khandbari	250
7	Gandak	15000		23	Phidim	240
8	Modi Khola	14800		24	Surnaiyagad	200
9	Devighat	14100		25	Doti	200
10	Sunkoshi	10050		26	Ramechhap	150
11	Puwakhola	6200		27	Terhatum	100
12	Chatara	3200		28	Duhabi Multifuel	39000
13	Panauti	2400		29	Hetauda	14410

14	Tatopani/Myagdi	2000		30	Simikot (Solar)	50
15	Seti (Pokhara)	1500		31	Gamgadhi (Solar)	50
16	Phewa (Pokhara)	1000		32	Small Hydropower (Isolated)	4536
					Total	531,040

Following hydro power plants were selected for analysis purpose on the basis of above mentioned Screening Procedure.

- Trishuli Hydro Power Plant (THPP)
- Devighat Hydro Power Plant (DHPP)
- Sunkoshi Hydro Power Plant (SHPP)
- Modikhola Hydro Power Plant (MoHPP)
- Marshyangdi Hydro Power Plant (MHPP)
- Madhya Marshyangdi/ Mid Marshyangdi Hydro Power Plant (MMHPP)
- Kaligandaki Hydro Power Plant (KHPP)

Energy Generation Profile

The energy generation profile for the seven listed hydropower plants were generated by taking the monthly power generation of each of the power plants for five consecutive years from F.Y. 2066/67 to 2069/70 and for comparison purpose the latest generation was compared with the four years average generation.

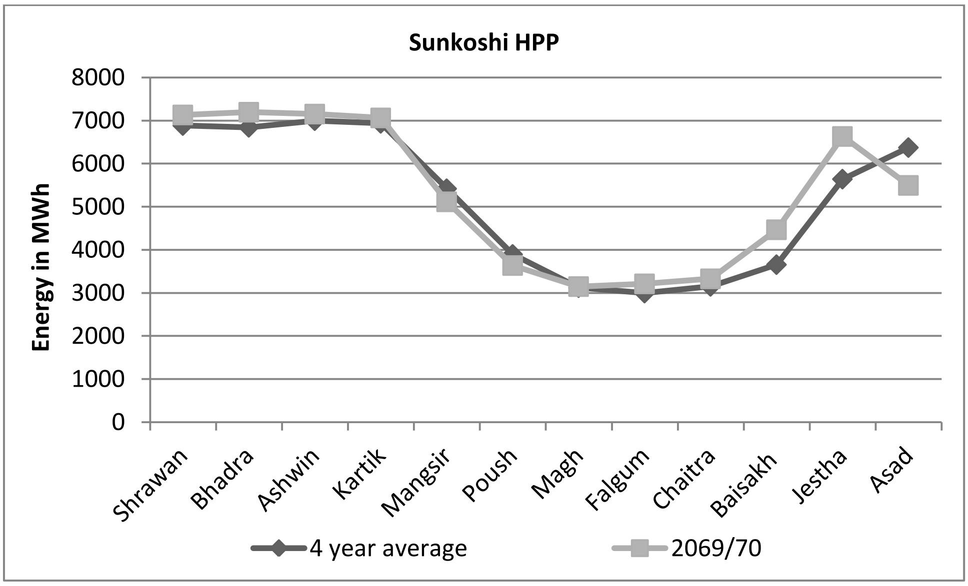

Figure 1: Energy Generation Profile of Sunkoshi HPP

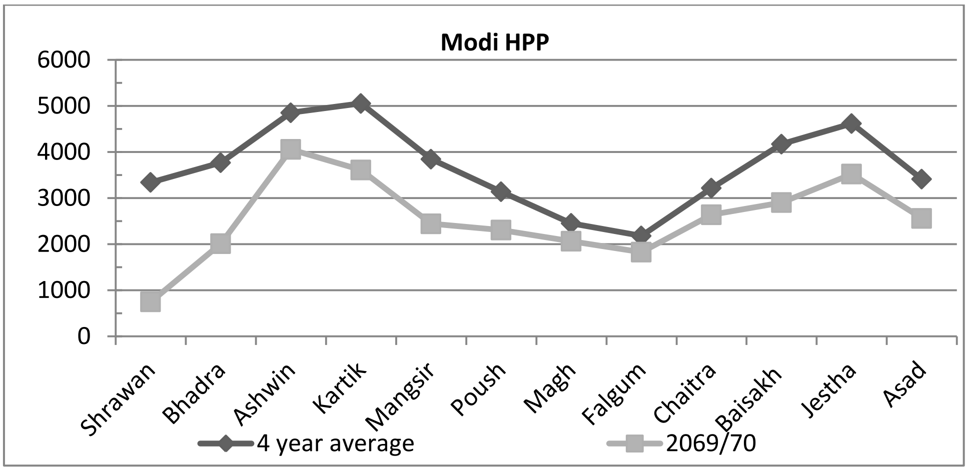

Figure 2: Energy Generation Profile of Modi HPP

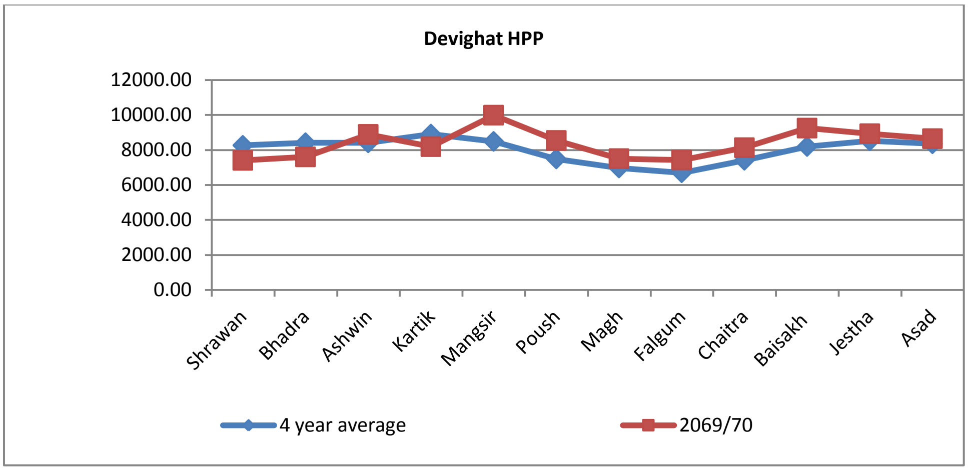

Figure 3: Energy Generation Profile of Devighat HPP

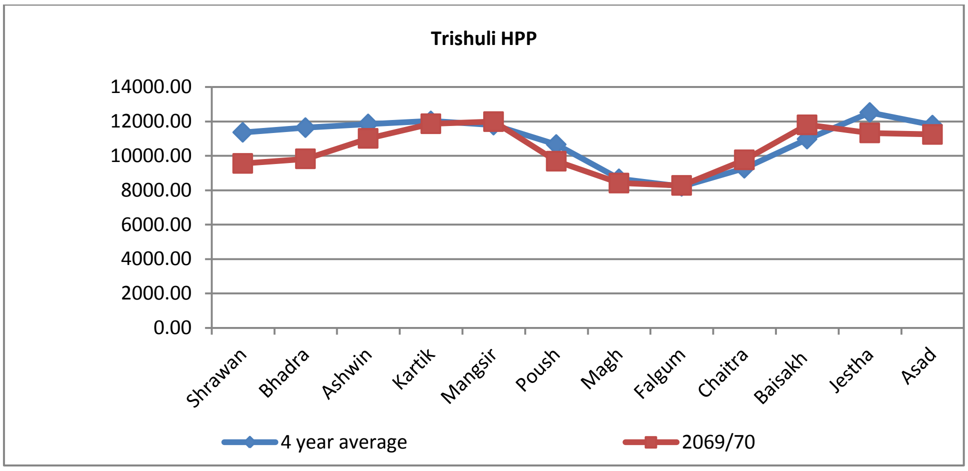

Figure 4: Energy Generation Profile of Trishuli HPP

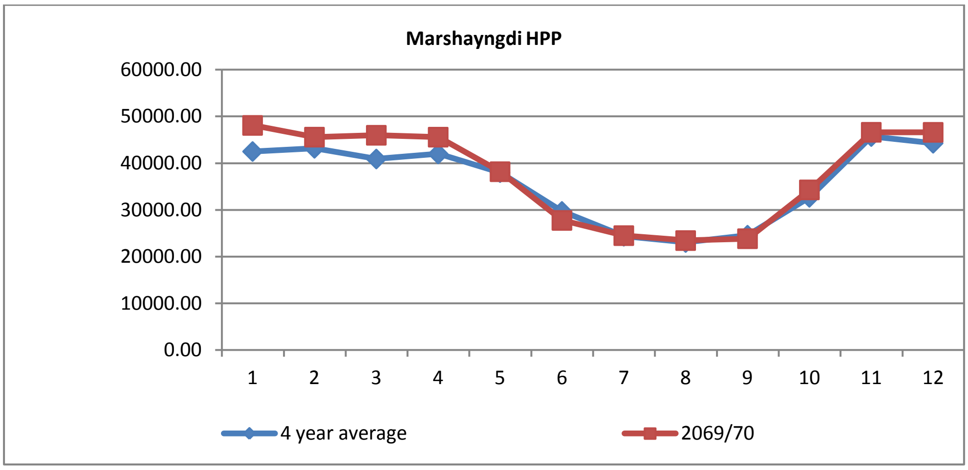

Figure 5: Energy Generation Profile of Marshyangdi HPP

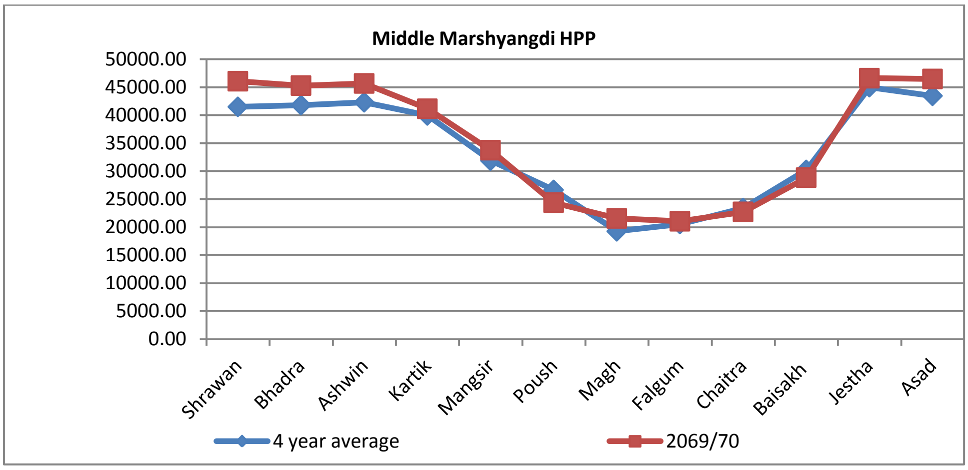

Figure 6: Energy Generation Profile of Middle Marshyangdi HPP

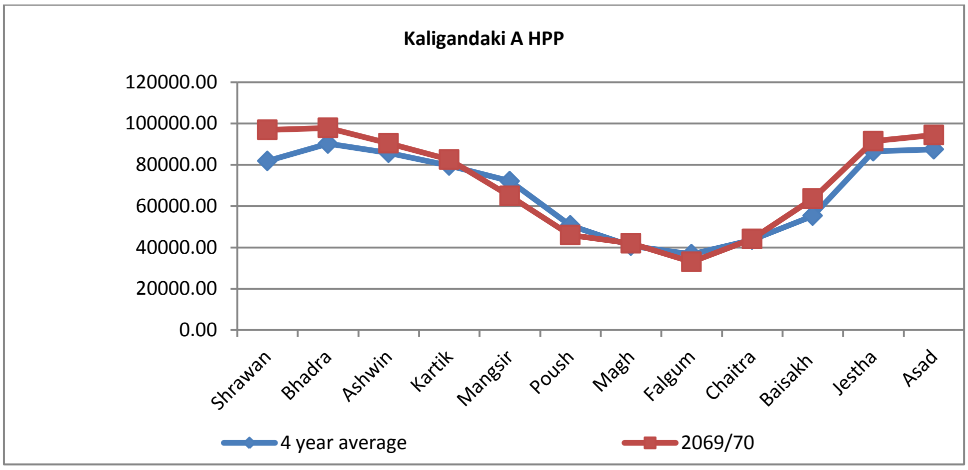

Figure 7: Energy Generation Profile of Kaligandaki A HPP

From the above graphs, except Modi HPP all other power plants generation is following the energy profile of 4 year average. Some of the power plants generation even exceeds the energy profile on account of improved river discharge, increase loading along with rigorous Operation & Maintenance practices, timely decisions and operational support resulting in greater performance and condition of the power plant.

Performance Assessment

Capacity Factor

The average annual generation of four consecutive years from F.Y. 2066/67 to 2069/70 has been taken as a reference for calculating the Capacity factor as defined in section Capacity Factor. Table given below represents the data taken as reference and Figure 5–8: Capacity Factor of Power Plants gives the result.

Table 2: Annual Design Generation & Average Annual Energy Generation

S. No.	Power Stations	Capacity in MW	Annual Design Generation in GWh	Average Annual Energy Generation in MWh	Capacity Factor
1	Kaligandaki A	144.00	842	827728.00	98%
2	Mid-Marshyangdi	70.00	398	408714.69	103%
3	Marshyangdi	69.00	462.5	439748.90	95%
4	Trishuli	24.00	163	129265.33	79%
5	Devighat	15.00	114	93245.24	82%
6	Modi	14.80	92.5	41762.78	45%
7	Sunkoshi	10.05	70	63438.50	91%

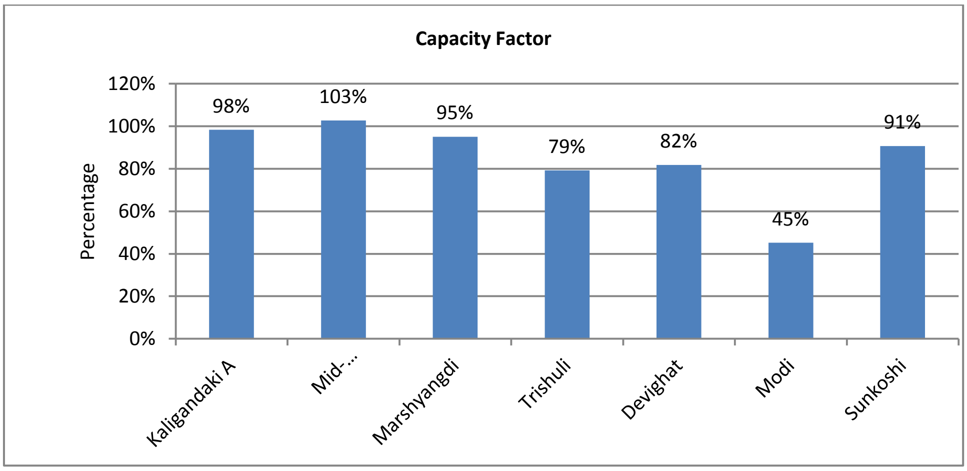

Figure 8: Capacity Factor of Power Plants

The above graph shows that Mid-Marshyangdi HPP stands out above others as its average annual energy generation exceeds that of its annual design energy generation whereas Modi HPP has the lowest value on account of its largely unsatisfactory performance during rainy seasons mainly due to sub-optimal design of head works, inadequate sediment handling facilities leading to erosion, cavitations and vibration of electromechanical components.

Plant Factor

The average annual generation of four consecutive years from F.Y. 2066/67 to 2069/70 has been taken as a reference for calculating the Plant factor as defined in section Plant Factor. Table given below represents the data taken as reference and figures 5 to 9 give the result.

Table 3: Plant Factor of Power Plants

S. No.	Name of Powerstation	Average Annual Energy Generation in MWh	No. of Units	Plant Factor
1	Kaligandaki A	827728.00	3	66%
2	Middle Marshyangdi	408714.69	2	67%
3	Marshyangdi	439748.90	3	73%
4	Trishuli	129265.33	7	61%
5	Devighat	93245.24	3	71%
6	Modi	41762.78	2	32%
7	Sunkoshi	63438.50	3	72%

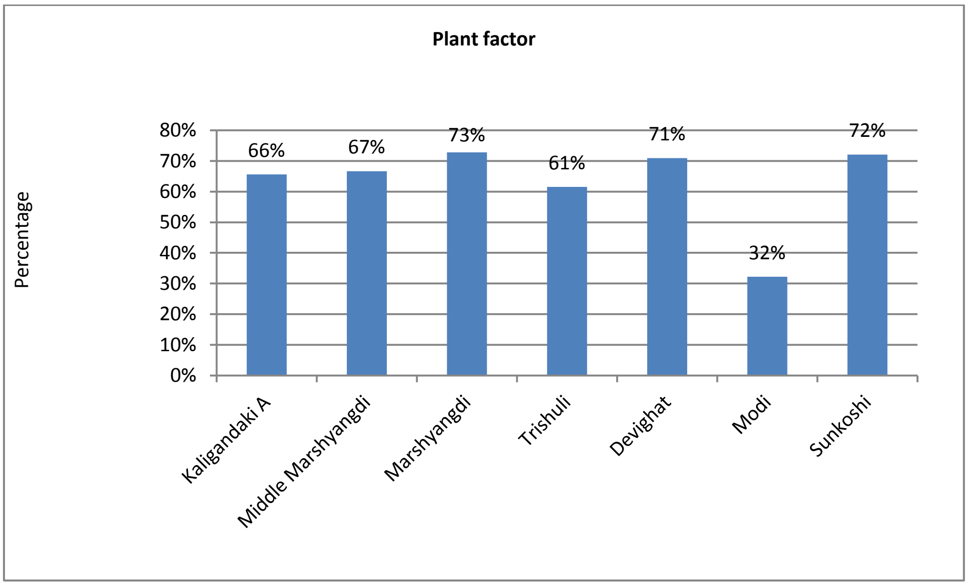

Figure 9: Plant Factor of Power Plants

Again Modi HPP has the lowest Plant Factor on account of its lower annual energy generation due to problems in headwork, electromechanical components for extensive period of time whereas Marshyangdi HPP has the highest Plant Factor on account of its higher annual energy generation reflecting good condition of power plant. Maintenance works limited to routine repair & maintenance along with periodic overhauling.

The above data shows that the average plant factor of HPP varies with maximum of 73% for Marshyangdi HPP and minimum of 32% for Modi HPP. With an exception of Modi HPP all the capacity factors are within and above industry best practice of between 50 and 80% (Ekeh, 2008).

Performance Factor

NEA gives a target generation to achieve for each of power plants on a monthly basis. The target or forecast is generated on account of the previous generation trend, operation & maintenance of HPPs. Performance Factor gives the measure of the target set versus actual generation.

Table 4: Yearly Variation in Performance Factor

S.No.	Power Stations	Performance Factor				Average Performance Factor
		2066/67	2067/68	2068/69	2069/70	
1	Kaligandaki A	104.29	99.87	106.76	100.16	102.77
2	Middle Marshyangdi	88.94	97.44	106.52	101.79	98.67
3	Marshyangdi	96.29	96.75	99.75	99.81	98.15
4	Trishuli	101.73	90.34	96.82	84.85	93.43
5	Devighat	139.19	74.14	105.09	88.9	101.83
6	Modi	82.28	97.59	52.94	53.89	71.68
7	Sunkoshi	102.02	98.96	106.03	100.14	101.79

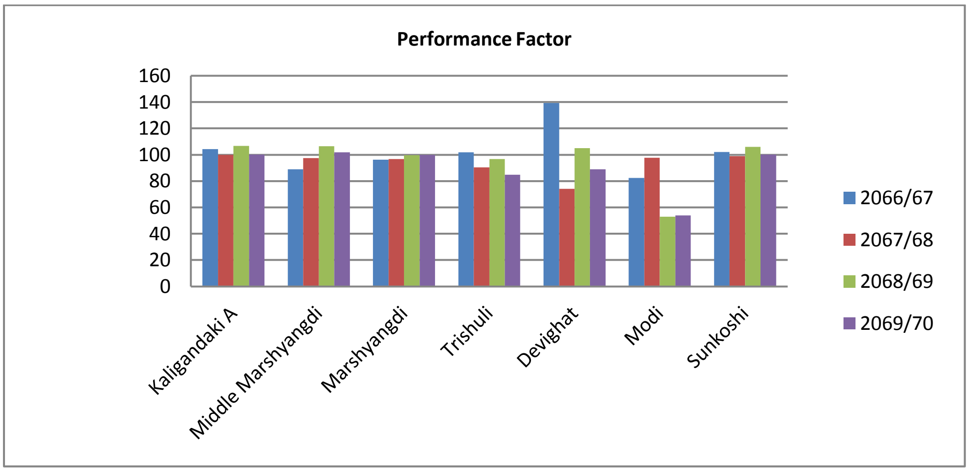

Figure 10: Yearly Variation in Performance Factor

Modi HPP plant has got more variations compare to others owing to the repair & maintenance works in the electromechanical as well as civil components resulting in lower actual generation than forecasted.

The average Performance Factor for the power plants from F.Y. 2066/67 to 2069/70 is shown in the figure below.

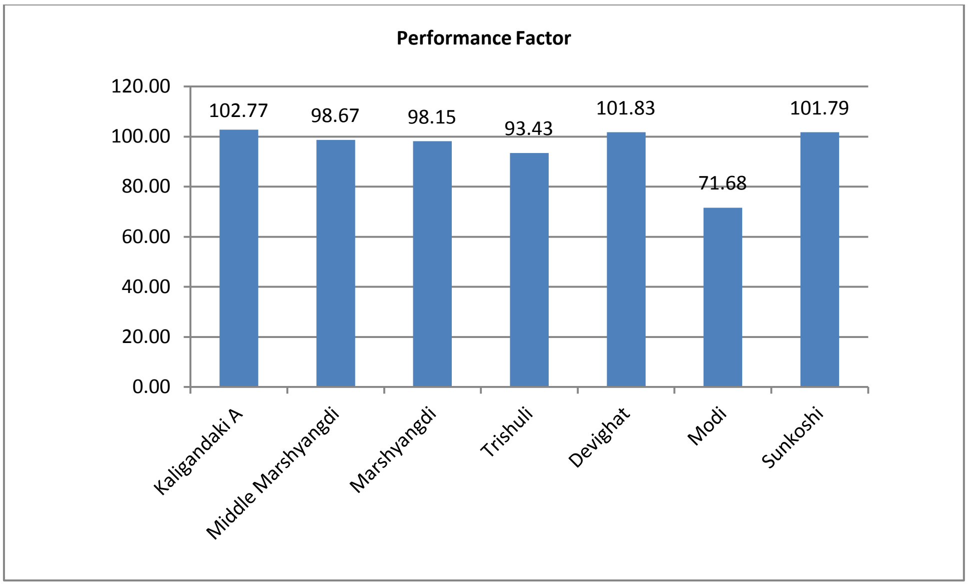

Figure 11: Performance Factor of Power Plants

Availability Factor

The availability factor has been calculated as defined in section 5.1.5. For comparison purpose an availability factor of 90% has been taken as a reference (Bureau of Reclamation, 2003). The difference is shown in the table given below and outlined in the figure 5-12.

Table 5: Deviation of Availability from reference value

S.No.	Name of Powerstation	Availability (%)		Difference
		Average	Preferred Value	
1	Kaligandaki A	86.19	90	-3.81
2	Middle Marshyangdi	80.00	90	-10.00
3	Marshyangdi	96.33	90	6.33
4	Trishuli	77.99	90	-12.01
5	Devighat	98.21	90	8.21
6	Modi	79.33	90	-10.67
7	Sunkoshi	95.55	90	5.55

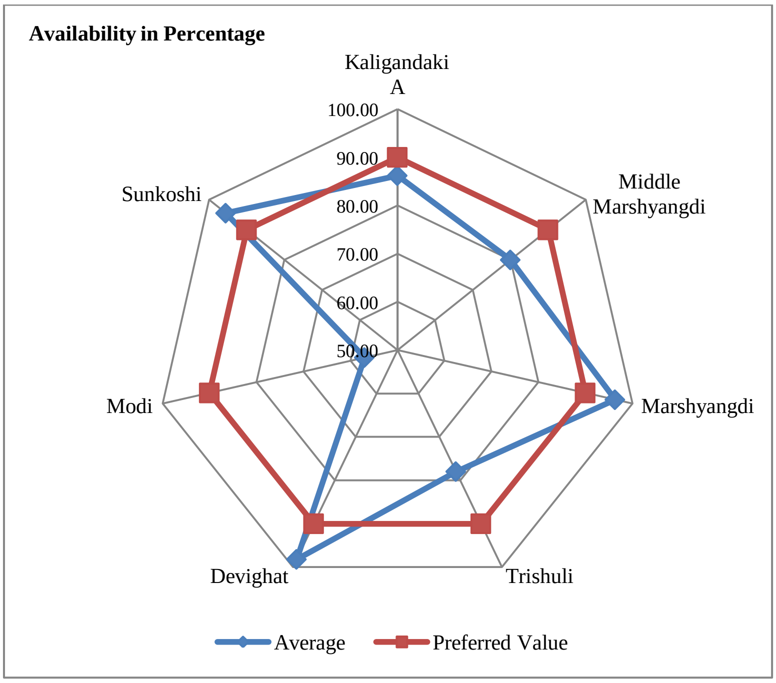

Figure 12: Availability of Power Plants

Staffing Level

Staffing Level takes in consideration of number of employees which has been allocated for the carrying out day to day operation & maintenance of power plants. The number of employee has been subjected to review from time to time. The time period taken for analysis purpose is four years as shown in table below.

Table 6: Staffing Level of Power Plants

S.No.	Name of Powerstation	No. of Employee per MW			
		2066/67	2067/68	2068/69	2069/70
1	Kaligandaki A	0.89	0.99	1.15	1.12
2	Middle Marshyangdi	1.19	1.06	0.94	0.96
3	Marshyangdi	1.07	1.32	1.41	1.41
4	Trishuli	5.5	5	3.92	3.75
5	Devighat	6.73	5.33	5.47	4.87
6	Modi	3.78	2.7	2.84	2.77
7	Sunkoshi	6.77	4.78	5.67	5.87

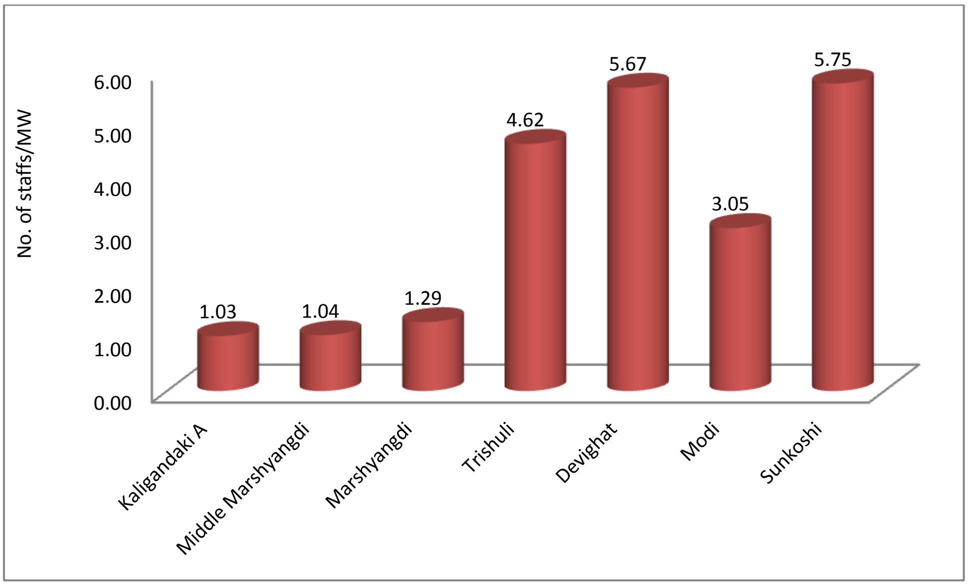

Figure 13: Average Staffing Level

Economic Efficiency

Economic Efficiency as defined in section 2.7.2.3 has been calculated for F.Y. as shown in the table below:

Table 7: Generation Cost of Power Plants

S. No.	Name of Powerstation	Generation Cost (Rs. per kWh)		
		2066/67	2067/68	2068/69
1	Kaligandaki A	3.05	3.1	2.79
2	Middle Marshyangdi	4.89	5.5	4.93
3	Marshyangdi	2.12	1.96	1.96
4	Trishuli	2.61	2.37	2.34
5	Devighat	1.55	1.74	1.77
6	Modi	3.71	2.76	4.91
7	Sunkoshi	2.08	1.83	2.11

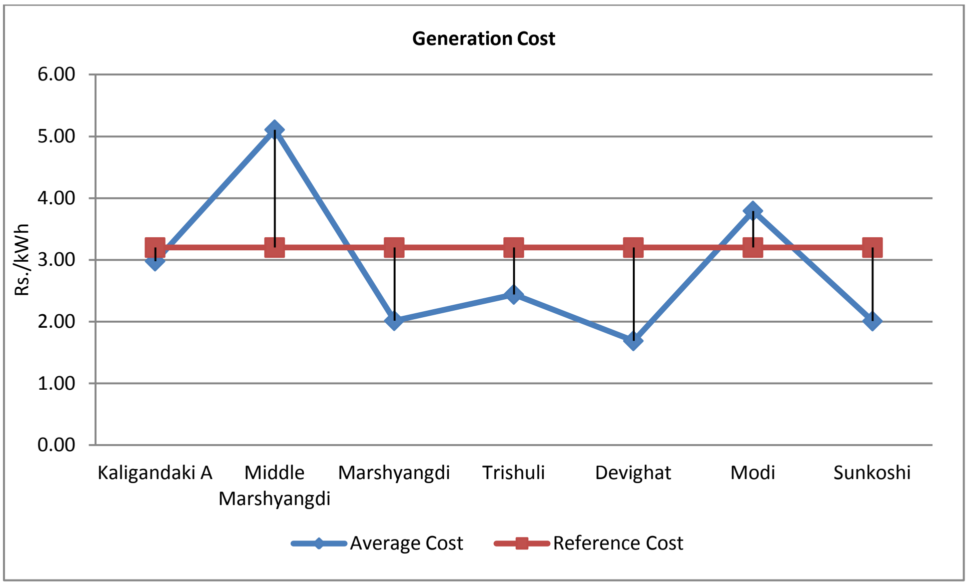

Figure 14: Average Generation Cost Vs Reference Cost

The reference cost has been taken as an average between three cents/kWh and five cents/kWh which converted to NRs. becomes NRs. 3.2. (Jean & Marie, 2004) Middle Marshyangdi HPP has got higher deviation with respect to reference cost owing to the high amount of interest whereas Modi HPP has got higher cost than reference cost on account of its higher O&M expenditure along with interest. The detail of the costs taken into consideration is given in Appendix 4.

Station Loss

The station loss for the power plants from F.Y. 2066/67 to 2069/70 is shown in the table below.

Table 8: Station Loss of Power Plants

S. No.	Power Stations	Station Loss (%)			
		2066/67	2067/68	2068/69	2069/70
1	Kaligandaki A	0.20%	0.33%	0.30%	0.27%
2	Mid-Marshyangdi	1.85%	1.92%	1.81%	1.70%
3	Marshyangdi	1.26%	1.26%	1.57%	2.06%
4	Trishuli	1.29%	0.40%	0.44%	0.40%
5	Devighat	2.32%	2.54%	1.93%	1.81%
6	Modi	2.84%	2.39%	2.72%	3.69%
7	Sunkoshi	0.30%	1.01%	0.54%	0.55%

Taking the average of the station loss and comparing it with the permissible value of 2%.

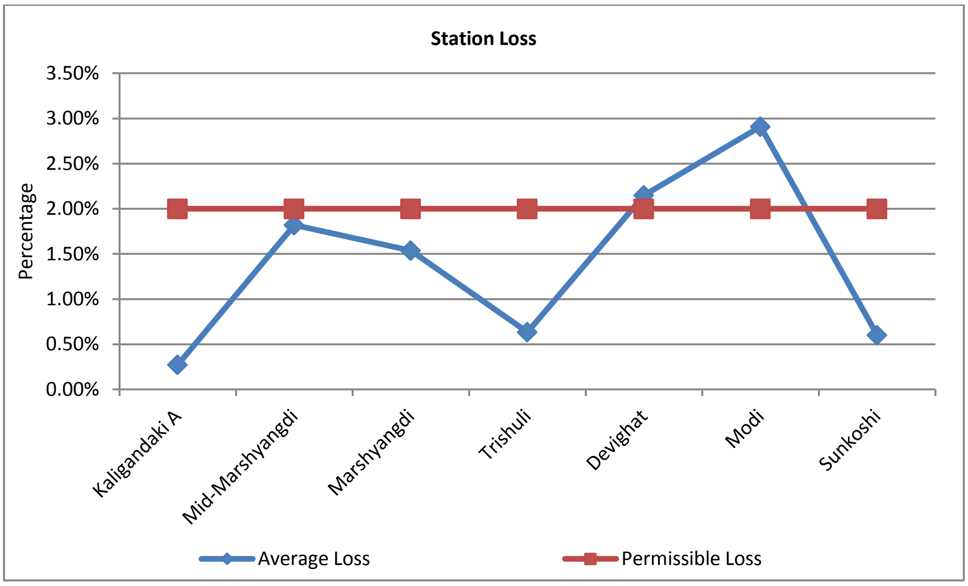

Figure 15: Average Station Loss vs Permissible Loss

Modi HPP has got higher value than the permissible limit i.e. its utilized energy is less than that of available energy.

Annual Energy Generation per Installed Capacity:

The annual energy generation per installed capacity for the power plants from F.Y. 2066/67 to 2069/70 is shown in the table below.

Table 9: Annual Energy Generation per MW

S. No.	Power Stations	GWh/MW			
		2066/67	2067/68	2068/69	2069/70
1	Kaligandaki A	5.28	5.38	5.98	5.87
2	Mid-Marshyangdi	5.57	5.39	6.08	5.95
3	Marshyangdi	5.87	6.13	6.46	6.54
4	Trishuli	5.64	5.34	5.62	6.13
5	Devighat	3.45	4.94	7.01	7.54
6	Modi	6.4	4.05	2.34	3.85
7	Sunkoshi	5.71	6.01	6.61	6.32

The designed annual energy generation per installed capacity is given below

Table 10: Designed Annual Energy Generation per MW

S. No.	Power Stations	Capacity in MW	Annual Design Generation in GWh	Design GWh/MW
1	Kaligandaki A	144	842	5.85
2	Mid-Marshyangdi	70	398	5.69
3	Marshyangdi	69	462.5	6.7
4	Trishuli	24	163	6.79
5	Devighat	15	114	7.6
6	Modi	14.8	92.5	6.25
7	Sunkoshi	10.05	70	6.97

Comparing the average annual energy generation of the power plants with their designed annual energy generation we get the following results:

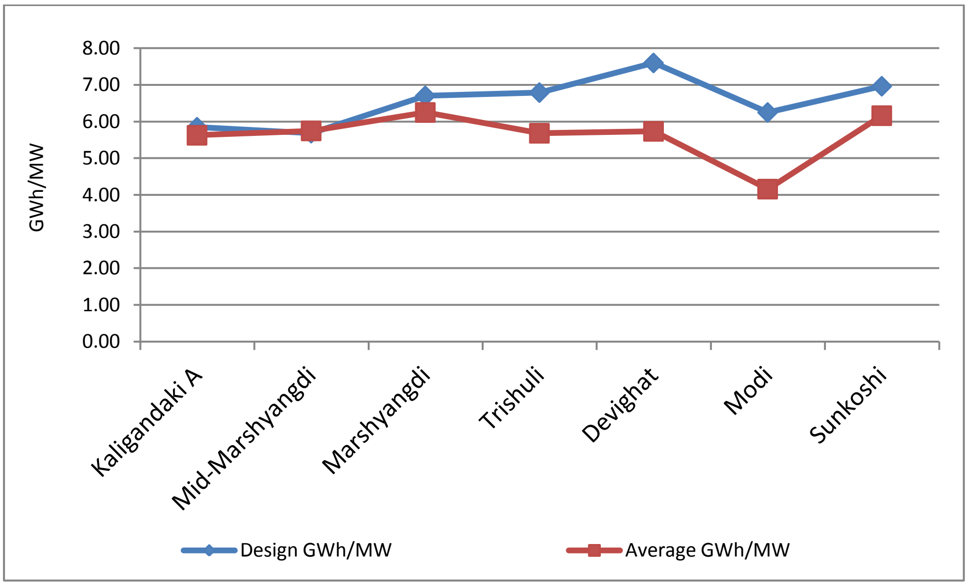

Figure 16: Designed GWh/MW Vs Average Annual GWh/MW

The average annual energy generation per installed capacity is high for Mid Marshyangdi HPP whereas least for Modi HPP on account of the annual generation achieved.

Conclusion

The energy generation profile for the seven listed hydropower plants were generated in which except Modi HPP has all other power plants generation is following the energy profile of four year average. Some of the power plants generation even exceeds the energy profile on account of improved river discharge, increase loading along with rigorous Operation & Maintenance practices, timely decisions and operational support resulting in greater performance and condition of the power plant.

Modi HPP has the lowest Capacity factor Plant Factor on account of its lower annual energy generation due to problems in headwork, electromechanical components for extensive period of time and largely unsatisfactory performance during rainy seasons mainly due to sub-optimal design of head works, inadequate sediment handling facilities leading to erosion, cavitations and vibration of electromechanical components. Marshyangdi HPP has the highest Plant Factor on account of its higher annual energy generation reflecting good condition of power plant. Maintenance works limited to routine repair & maintenance along with periodic overhauling.

Economic Efficiency results Middle Marshyangdi HPP has got higher deviation with respect to reference cost owing to the high amount of interest whereas Modi HPP has got higher cost than reference cost on account of its higher O&M expenditure along with interest. The average annual energy generation per installed capacity is high for Mid Marshyangdi HPP whereas least for Modi HPP on account of the annual generation achieved.

Among the seven hydropower plants selected owned with Francis turbine, Marshyangdi HPP plant whereas Modi HPP is least plant. Technical aspect of hydropower plant to have great importance is a must in-order for a hydropower plant to have efficient and effective operation for a longer period of time.

Modi HPP shows energy generation is poor with respect to its designed annual energy generation on account of excessive plant failure, outages. This means that most of its capacity remains unutilized for major part of the year and so cost would be high as well. However, if scheduled routine maintenance of the plant is significantly improved along with timely rehabilitation, high generation can be attained and cost of generation will be considerably economical. It is concluded that Modi HPP should be looked upon for Rehabilitation It also undergoing such rehabilitation of civil works along with electro mechanical works.

Hence the performance evaluation of hydropower plants which are currently on operation is one of the important factors in generation of energy.

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