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# Evaluation of Transmission Pricing Methodologies for Nepalese Power System in Restructured Environment

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**Abstract**

The rapidly changing business environment for electric power utilities all around the world has resulted in unbundling of services provided by these utilities. Likewise, the various discussions and the few initiations have taken place to unbundle the vertically integrated structure of Nepal Electricity Authority (NEA). Recently, the government has formed National Transmission Grid Company (NTGC), paving the way for formation of a separate entity to work for development and operation of electricity transmission lines. Transmission services to be provided by NTGC shall be priced in such a way that it is economically beneficial to both the wheeling utility and the customers and it ensures the recovery of the cost incurred in providing services. This research reviews and evaluates, for Integrated Nepal Power System (INPS), the various transmission pricing methodologies. Firstly, annual required revenue is evaluated. Then, the Marginal transmission pricing method has been evaluated. Annual Marginal Network Revenue (AMNR) received based on this method sums only to 29.84% of the total annual revenue expected by NTGC. Marginal transmission pricing method though promotes economic efficiency and congestion avoidance, fails to recover the total cost. The deficit revenue is then allocated, as complementary charge, to Generators/Loads using Rolled-In or Embedded Cost transmission pricing method. Postage Stamp method charges uniformly all Generators/Loads irrespective of the topological distribution and actual usage of INPS whereas MW-Mile method considers the actual usage of INPS. Bialek's Tracing Algorithm seemed fairer then Generalized Distribution Factors method while determining the actual usage of every transmission lines of INPS by each Generator/Load. It is concluded that the combination of both Marginal Pricing and Bialek's Algorithm based pricing method would be most suitable for pricing the transmission services of INPS. The proposed composite transmission pricing method would ensure economic efficiency, congestion avoidance and the cost recovery.

**Keywords**

Electricity market – Transmission Pricing – Economic efficiency – Cost recovery

## 1. Introduction

The rapidly changing business environment for electric power utilities all around the world has resulted in unbundling of services provided by these utilities. Wheeling of electrical energy (transmission services) is one of the more prevalent of such unbundled services. In fact, today there are enterprises whose main function is to only provide wheeling ("transmission grid") services [1].

Electricity market in Nepal, can be considered to be Monopsony market with the competition in the generation service only. Nepal Electricity Authority (NEA), the government utility, holds the monopoly of transmission and distribution services and has its own generating facilities as well. So, NEA is a Vertically Integrated Utility (VIU).

However, the recent statements from the Government of Nepal indicate the initiation to unbundle the services of NEA. Recently in F.Y. 2072/73, the government has formed National Transmission Grid Company (NTGC) [2], paving the way for formation of a separate entity to work for development and operation of electricity transmission lines.

Proposed NTGC plans to introduce Transmission Tariff (wheeling charge) to generate resources. Wheeling

Charge refers to the amount levied to the wheeling entities for the usage of transmission facilities. Transmission Tariff shall be chosen such that the costs of providing transmission services is fully recovered and the tariff imposed on the users of transmission services is principally efficient.

This paper seeks to evaluate the transmission pricing methodologies found in various literature. For that purpose, firstly, the proper model for Nepalese electricity market in restructured environment has been assumed. Then, the required annual revenue of Integrated Nepalese Power System (INPS), the network as provided in [2], is evaluated. After that, the marginal transmission pricing paradigm and the cost recovery issue associated with it has been evaluated for Integrated Nepalese Power System (INPS). The amount of cost not so recovered, as the complementary charge, has been allocated to generators on the basis of rolled-in (embedded cost) transmission paradigm.

## 2. Electricity Market Model

Based on recent developments and issues, a pool based electricity market with single purchasing agency is considered to be most suitable electricity market model. It is assumed that there are various generation companies (GENCOs) who produces and sells electricity into the pool, NTGC who owns, builds and operates transmission facilities, National Power Trading Company (NPTC) being a single purchaser of electricity is responsible for market and contracts settlement and the various distribution companies (DISCOs) who purchases electricity from the pool and sells it to the customers. All the entities involved in the electricity market are assumed to operate under the regulation of National Electricity Regulatory Commission (NERC). Figure 2.1 depicts the assumed electricity market model showing how the energy and money flows within the market.

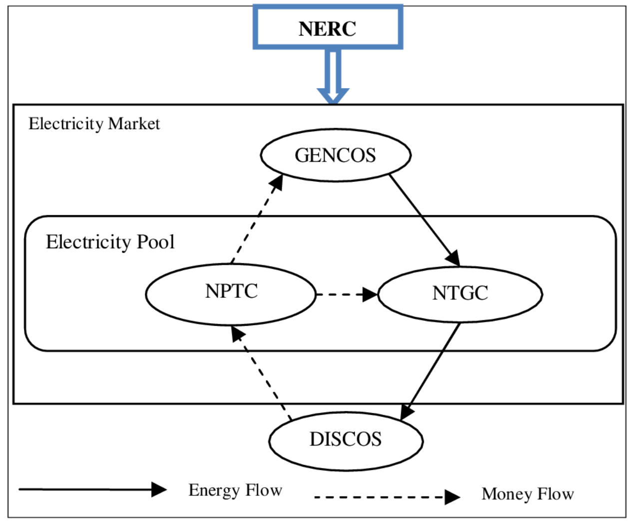


**Figure 2.1:** Assumed Electricity Market Model

## 3. Evaluation of Required Annual Revenue of INPS

Firstly, the total network cost of INPS is evaluated summating the cost of transmission lines. This cost is assumed to be present value of the network cost and annuitized for 40 years with discount rate of 10% using Equation 3.1 and the evaluated annuitized cost is considered as the required annual revenue of INPS.

$$A = \frac{PV}{\frac{(1-(1+r)^{-n}}{r}} \tag{3.1}$$

The total present value of INPS and required annual revenue is evaluated to be 253.11 and 39.16 million USD respectively. The cost of transmission lines is taken from [3].

## 4. Evaluation of Marginal Transmission Pricing Method

Marginal Network Revenue of INPS is evaluated using the 4.1 [4] and Network Revenue evaluated is multiplied by 8760 hours to determine the Annual Marginal Network Revenue (AMNR) of INPS.

$$\mathrm{NR} = \sum_{l} \rho_{l,out} \cdot P_{l,out} - \rho_{l,in} \cdot P_{l,in} \tag{4.1}$$

Where:

**NR** = Network Revenue for each transmission network $l$

$\rho_{l,in}$ = Nodal price at incoming node of line $l$

$P_{l,in}$ = Active power flow into one end of the line $l$

$\rho_{l,out}$ = Nodal price at outgoing node of line $l$

$\rho_{l,in}$ = Power flow from node $i$ to $j$.

$P_{l,out}$ = Active power flow out of another end of line $l$

$\rho_{l,in}$, $P_{l,in}$, $\rho_{l,out}$, $\rho_{l,in}$ and $P_{l,out}$ are obtained from optimal power flow results.

### 4.1 Optimal Power Flow of INPS

AC Optimal Power Flow (ACOPF) of INPS is carried out in MATPOWER 5.1 which is a power system simulation software based on MATLAB environment. The objective functions and constraints of the objective function for OPF are as given in [5]. For carrying out OPF, generator cost function for all the generators is assumed to be USD 68 per MWh which is the globalized cost of energy for hydropower [4]; conductor thermal limits are considered as the line flow limits; $v_m^{i,max}$ and $v_m^{i,min}$ are considered 1.1 p.u. and 0.9 p.u. respectively; the real and reactive power limits are that of the respective generators' limits.

The maximum nodal price is observed at Birgunj and is 79.60 USD per MWh. The minimum nodal price is observed at Bhotekoshi as wee as other few generators and is 68 USD per MWh. The nodal price variation across INPS is shown in Figure 4.1.

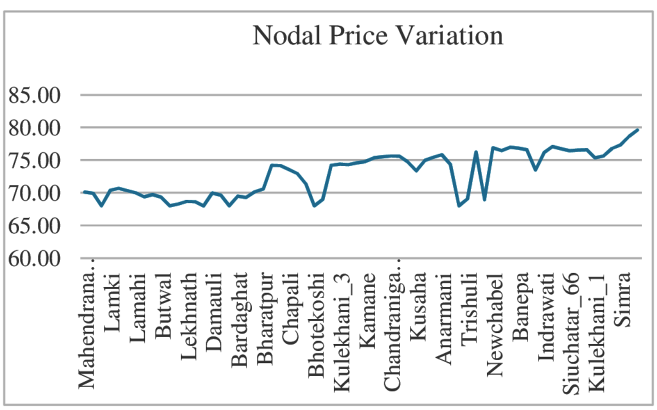


**Figure 4.1:** Nodal Price Variation across INPS

### 4.2 AMNR of INPS

Among the 132 kV Transmission Lines, the maximum and minimum AMNR is received from Marsyangdi-Siuchatar 132 kV Transmission Line and Chandranigahapur-Dhalkebar 132 kV Transmission Line respectively. The variation in the AMNRs of the 132 kV Transmission Line is given in Figure 4.2.

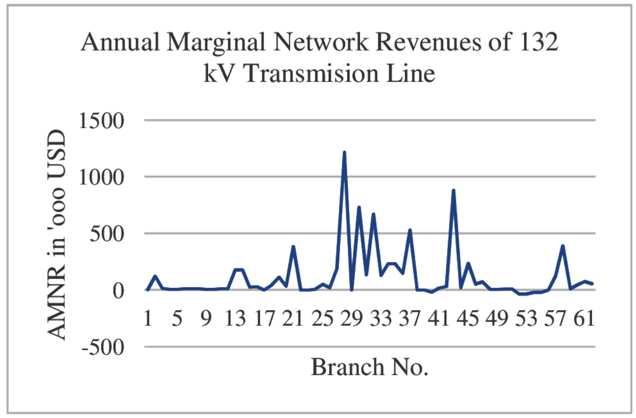


**Figure 4.2:** AMNR of 132 kV Transmission Lines

Similarly, among the 66 kV Transmission Lines, the maximum and minimum AMNR is received from Devighat-Newchabel 66 kV Transmission Line and Trishuli-Devighat 66 kV Transmission Line respectively. The variation in the AMNRs of 66 kV Transmission Lines is given in Figure 4.3.

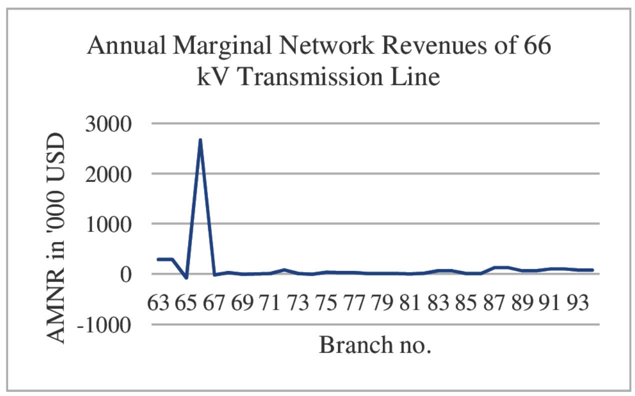


**Figure 4.3:** AMNR of 66 kV Transmission Lines

### 4.3 Cost Recovery Issue

It is found that AMNR of INPS is 11.69 million USD which is only 29.84% of the required annual revenue. So the remaining 70.16% has to be allocated to either generators or loads as the complementary charge. Here, the complementary charge has been allocated to generators by Rolled-In transmission pricing method.

# 5. Evaluation of Rolled-In (Embedded Cost) Transmission Pricing Method

Among various methods under this paradigm, the postage stamp method and flow based MW-Mile method has been evaluated.

## 5.1 Postage Stamp Method

This transmission pricing method allocates transmission charges based on the magnitude of the transacted power that is usually measured at the time of system peak. This method has the advantage of simplicity and cost recovery; however it ignores the actual system power flow.

The transmission charges is calculated using the formula:

$$TC_t = TC \times \frac{P_t}{P_{\text{peak}}} \tag{5.1}$$

Where,

$TC_t$ = cost allocated to the generator $t$

$TC$ = total transmission cost

$P_t$ = power generated by generator $t$ at the time of system peak

$P_{\mathbf{peak}}$ = system peak generation

## 5.2 MW-Mile Method

MW-Mile (MWM) allocates fixed costs to users based on the "extend of use" of each network facility. The method ensures the full recovery of fixed transmission costs and reflects, to some extent, the actual usage of transmission systems. [6]

In the MW-Mile method, there are three different approaches in relation with how users that cause *counter-flows* in the network are charged. In addition, total charges for the network facilities can be based either on the *unused (total) transmission capacity* or on the *used capacity* of the facilities. When based on the unused transmission capacity, full recovery of the embedded transmission cost is guaranteed.

In the unused or used absolute MW-Mile, charges are being calculated based on the magnitude of the MW-Miles of network used from each user, ignoring the direction of the power flow on the circuit. It is evaluated using Equation 5.2.

$$TC_{t,\text{unused}} = \sum_{k \in K} \left( C_K \cdot \frac{|F_{t,k}|}{\sum_{t \in T} |F_{t,k}|} \right) \tag{5.2}$$

Where,

$C_k$ = the cost of line $k$

$F_{t,k}$ = the power flow on line $k$ caused by generator $t$

$K$ = the set of transmission lines

It is seen from Equation 5.2, in the MW-Mile method, $F_{t,k}$, the power flow on line $k$ caused by generator $t$ has to be determined or the power flow on a particular line has to be traced to know the contribution of generators on that line.

### 5.2.1 Evaluation of Power Tracing Methods

Among various power tracing methods found in literature, the following methods found in [7] are used in this study:

i. Generalized Generation Distribution Factors (GGDFs)
ii. Bialek's Upstream Tracing Algorithm

GGDFs determine the impact of each generator on active power flows; thus they can be negative as well. Since GGDFs are based on the dc model, they can only be used for active power flows. GGDFs are evaluated using the algorithm as described in [8].

In Bialek's upstream tracing algorithm, it is assumed that nodal inflows are shared proportionally among nodal outflows. This method uses a topological approach to determine the contribution of individual generators to every line flow based on the calculation of topological distribution factors. All the contributions are positive in this case. This method can deal with both dc power flow and ac power flows; that is, it can be used to find contributions of both active and reactive power flows. The algorithm is given in [8].

### 5.3 Cost Allocation to Generators

The complementary charge to be allocated to generators was evaluated to be 70.16% of the required annual revenue of INPS. This sum is allocated to all the generators by using postage stamp method, GGDF based MW-Mile and Bialek's upstream algorithm based MW-Mile method. The cost allocated to generators in dollar per MW generated by different methods is shown in Figure 5.1.

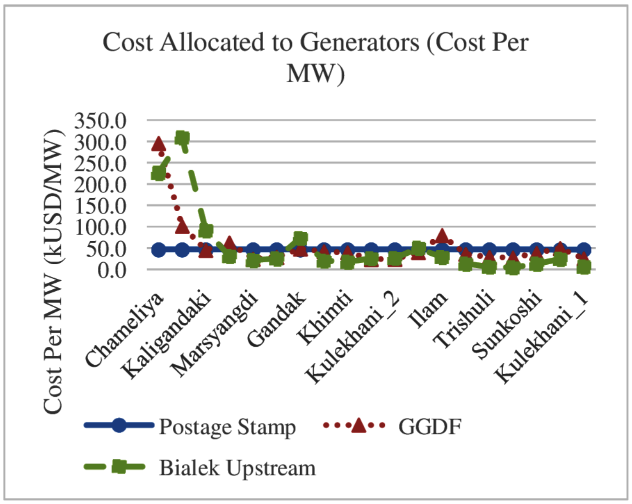


**Figure 5.1:** Cost Allocation to Generators

It is seen that, the postage stamp method is easy to implement and simple to understand, however, does not consider the actual usage of transmission network. So, it allocates the equal cost per MW generation irrespective of their location and usage of transmission lines. MW-Mile method based on power flow solutions, considers the actual usage of transmission network and requires the contribution of each generator/load on a particular line flow. For this GGDF and Bialek's Tracing factors have been evaluated. Since, Bialek's Tracing Factors gives the positive contribution only, it seems to be fairer than GGDF.

## 6. Conclusion

Based on above discussions, it can be concluded that despite of its advantages of maintaining economic efficiency the marginal pricing scheme is likely to fail in recovering the total system costs. In contrast to marginal pricing, Rolled-in (embedded) methods recover total system costs but fail to set incentives for either the efficient use of the system and for further expansion. So, the combination of both Marginal Pricing and Rolled-in (Embedded) Pricing Schemes if adopted would ensure both the economic efficiency and cost recovery. So, the composite of both Marginal and Rolled-In Transmission Pricing method would be more suitable in case of restructured Nepalese electricity market. In case of Rolled in Transmission Pricing scheme, MW-Mile is fairer than Postage-Stamp method and Bialek Upstream algorithm is fairer while evaluating the transmission usage.

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