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DESIGN AND DEVELOPMENT OF COMPETITIVE ELECTRICITY MARKET MODEL FOR NEPAL

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Abstract

In recent years, several efforts have been made to introduce a competitive wholesale electricity market in Nepal through the new electricity bill. However, in-depth studies on competitive electricity markets in the context of Nepal are almost nonexistent. This study tries to fill this research gap by developing a competitive wholesale electricity market model for Nepal. In this study, the market model is designed by dividing Nepal into six different bidding zones based on different provinces of Nepal. Two different types of pricing schemes, a uniform pricing scheme and a zonal pricing scheme, are implemented in the developed model. The study is based on the simplified model of the Interconnected Nepal Power System (INPS). The network is simplified by aggregating all the generators and loads within the same province and including the maximum power transfer capacity between two provinces. The results for two different schemes are compared based on the total cost of generation, energy surplus to the suppliers, and overall network losses. The result found that the uniform pricing schemes could lead to a lower production cost and higher network losses. The solution of a uniform pricing scheme was also found to be violating the transmission line constraint between Lumbini and Sudurpashim Province, leading to network congestion, signifying the need for re-dispatching and incurrence of dispatching costs in the uniform pricing model. The zonal pricing scheme results in lower network losses and lower surplus to suppliers and increases in overall production cost. These findings might be useful in the future for the implementation of a competitive wholesale market in Nepal.

Keywords: Electricity market, Electricity reform, Uniform pricing scheme, Zonal pricing scheme

1. Introduction

There has been a worldwide trend of deregulation in the electricity sector. The main driving factor toward the deregulation is to enhance consumer choice and the establishment of the market force to determine the cost of electricity based on supply and demand (Joskow, 2008). Nepal already made some effort towards deregulation by introducing private participation in generation independent power producers (IPPs), the formulation of Rastriya Prasaran Grid Company Limited (RPGCL), Vidhyut Utpadan Company Limited (VUCL), and the Electricity Regulatory Commission (ERC). The next step toward deregulation would be the provision of a competitive wholesale electricity market. There has been some attempt to introduce a competitive electricity market in the past through new electricity bills. Considering a potential transition of Nepal toward a more competitive electricity market in the near future, research needs to be done towards adopting the most suitable electricity market mechanism. This paper proposes a competitive day-ahead wholesale electricity market model in Nepal having six different bidding zones based on various provinces of Nepal.

1.1. Existing Market Structure in Nepal

The existing electricity market structure, shown in Figure 1 is characterized by the single buyer model, where only the electricity generation is open for multiple participants (Cretì and Fontini, 2019). The Nepal Electricity Authority (NEA) serves as a single buyer of electricity from various power producers through Power Purchase Agreements (PPAs) and also has a monopoly in the transmission and distribution system. There has been an ongoing unbundling in the transmission sector through the transfer in ownership from NEA to RPGCL. A private company, Butwal Power Company Limited (BPCL), and the

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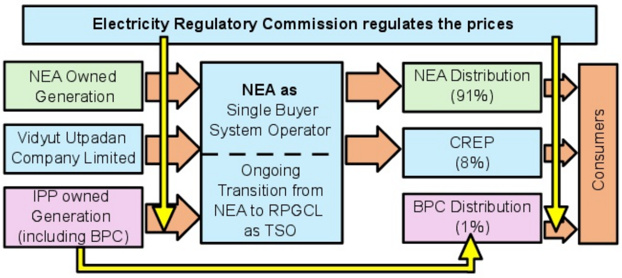

Figure 1. Existing Electricity Market in Nepal

Community Rural Electrification Programme (CREP) are also involved in the distribution sector, however the number of consumers they serve is significantly lower than NEA (Butwal Power Company Limited, 2023;Nepal Electricity Authority, 2023). There is the provision of the Electricity Regulatory Commission (ERC), responsible for regulating the electricity price purchased by NEA from the producers and the tariff for the consumers at the distribution level.

1.2. Wholesale Electricity Market Model

In the wholesale market model, all three aspects of the electrical supply chain, i.e., generation, transmission, and distribution, are separated from each other. The electrical supply chain is divided into generation companies (GENCO), transmission companies (TRANSCO), and distribution companies (DISCO). There is a provision for an independent market operator for operating the market and facilitating the trading of power between the producers and distributors. In the wholesale market model, power producers sell electricity to consumers either through bilateral contracts or through the spot market.

1.3. Future and Forward Market

In future and forward trading of electricity, the trading of electricity is based on the bilateral agreement between the suppliers and consumers. In the futures market, the contract regarding the exchange of electricity takes place on institutional exchanges, whereas in the forward market, exchange takes place outside the institutional exchanges (Malliaris and Ziemba, 2015).

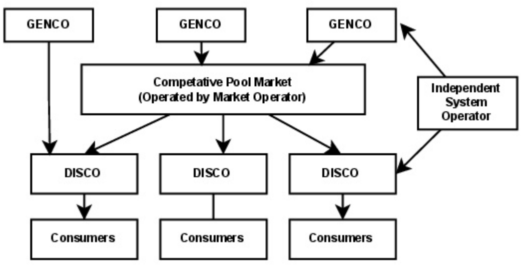

Figure 2. Wholesale Market Model

1.4. Energy Spot Market

The spot market can be used to reduce the risk associated with future and forward markets. In the spot market, electricity is traded near the time of actual delivery. If a consumer has already entered into a forward or futures market contract and the day of actual delivery approaches, the consumer may require more energy than previously predicted due to the updated forecast. In such a scenario, the extra energy can be purchased through the spot electricity market. The spot electricity markets are of two types: day-ahead market and intraday market. However, our study is limited to the day-ahead market only.

1.4.1 Day Ahead market

In the day-ahead market, trading of energy happens a day before the actual delivery of energy. The entire twenty-four-hour time slot is divided into multiple slots. The producers and consumers present their offers for each slot. Based on the market-clearing algorithm, it matches the supply and demand, and a market is cleared. After the market is cleared, all the generators and consumers are scheduled for power consumption. Figure 3 shows the time stamp for the day-ahead market implemented in Nordpool.

1.4.2 Intraday market

The intraday market begins after the publication of the market-clearing result for the day-ahead market. The intraday market facilitates participants of the day-ahead market to adjust their schedule based on the updated forecast of electricity (Glas et al., 2020). In this market, each participant submits their bid and offer prices and can view offers from others in a centralized platform. Based on their requirements, the participant can accept any offers presented on the platform through bilateral trading between participants.

1.5. Market Clearing in Day Ahead Market

Market-clearing algorithms are used to schedule the generators and load in day-ahead market clearing. For a

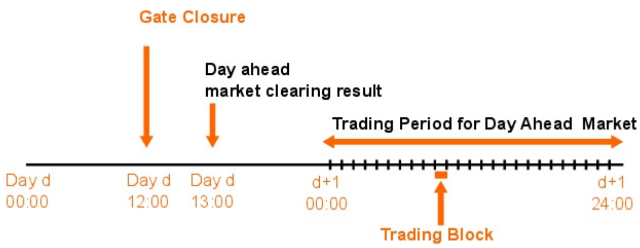

Figure 3. Day Ahead Market

two-bus system in Figure 4. The market-clearing algorithm is given by the optimization problem in Equation (1). The objective function is to maximize the social welfare subject to the various physical constraints and operational practices in the network.

$$\max_{\{y_i^D\},\{y_j^G\}} \left(\sum_i \lambda_i^D y_i^D - \sum_j \lambda_j^G y_j^G \right) \tag{1}$$

$$\text{subject to:} \quad \sum_i y_i^{D,A1} - \sum_j y_j^{G,A1} = B\Delta\delta \quad : \lambda^{s,A1}$$

$$\sum_i y_i^{D,A2} - \sum_j y_j^{G,A2} = -B\Delta\delta \quad : \lambda^{s,A2}$$

$$0 \leq y_i^D \leq P_i^D, \quad i = 1, \ldots, N_D$$

$$0 \leq y_j^G \leq P_j^G, \quad j = 1, \ldots, N_G$$

$$-P \leq B\Delta\delta \leq P$$

where
y_j^G, y_i^D : Accepted generation and demand quantities offered by generators $j \in \{1, \ldots, N_G\}$ and demand participant $i \in \{1, \ldots, N_D\}$
λ_j^G, λ_i^D : Prices of the various generator j and demand participant i
B : susceptance of the transmission line between the two areas
δ : Voltage angle between two buses
P : constraint on the power flow a transmission line can handle

The equality constraints ensure that in each region, the sum of generation demand and import equals zero. The inequality constraints put limits on generation and demand offers. The term $B\Delta\delta$ represents the physical constraint on how much a power transmission line can handle under DC power flow approximation.

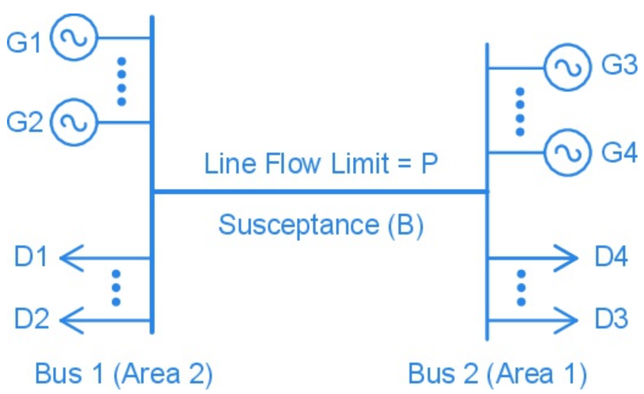

Figure 4. Two Bus System

1.6. Pricing Scheme in Day Ahead Market

Transmission lines have physical limits on the amount of power they can carry. When power flows are within these limits, electricity prices remain uniform across the entire market region, and there is no need to manage congestion. The pricing scheme is then called a uniform pricing scheme. However, if power flows exceed the line limits, congestion occurs and affects electricity prices. The presence of congestion in a network is handled through two different approaches: the zonal and the nodal pricing schemes (Kristiansen, 2025). Implementation of nodal pricing schemes can be seen in wholesale markets of Argentina, Chile, Mexico, New Zealand, Peru, Russia, Singapore, and several regions in the United States (U.S.). In a nodal pricing scheme, a fairly detailed representation of a network is considered, and the electricity price is computed at each node of the network. In zonal pricing schemes, the nodes in a network are aggregated into zones, and the market-clearing algorithm considers only inter-zonal transmission constraints. This assumption simplifies the constraint sets in the optimization problem and makes the computation relatively simple. Implementation of zonal pricing schemes can be seen in the Nord Pool market.

The price of day-ahead electricity is derived from solving the welfare maximization problem. Obtaining the solution for this maximization problem is a challenging task due to the non-convexity nature of the optimization problem (Liberopoulos and Andrianesis, 2016). The pricing scheme in the electricity market must also reflect the true value of electricity and provide investment incentives to every participant (Poudineh and Peng, 2017) and, at the same time, must be easy to compute.

In the nodal pricing scheme, the congestion is handled by the introduction of the transmission limits in a welfare maximization problem. The nonconvex nature of the optimization problem makes it difficult to solve the optimization problem. (Liberopoulos and Andrianesis, 2016). As an alternative, a zonal pricing scheme can be implemented. In the zonal pricing scheme, the whole electricity market is divided into different areas. The congestion within the area is neglected and is assumed to exist between the areas. This assumption will simplify the computation. Nodal pricing schemes accurately represent the true cost of electricity but are complex and computationally intensive. In contrast, zonal pricing schemes are simpler and less costly to compute but sacrifice pricing accuracy.

The major contribution of this paper is as follows:

- Implementation of 6 bidding zones based on the provincial divisions of Nepal.
- Modeling of the system using PowerWorld Simulator.

- Use a market-clearing algorithm to determine the pricing of each bidding zone in the network.
- Perform a comparison of zonal pricing and uniform pricing schemes.

The remainder of this paper is organized as follows. Section 2 describes the overall methods, including the modeling of INPS into various regions and implementation of zonal and uniform pricing schemes. Section 3 presents the result. Section 4 concludes this paper.

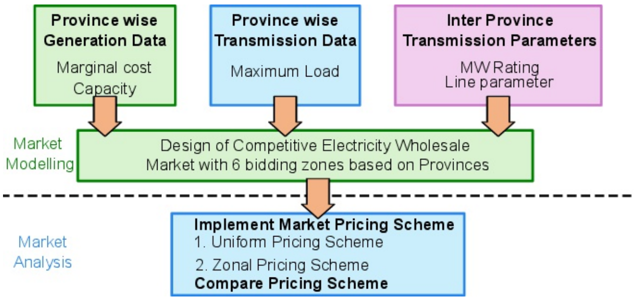

Figure 5. Methodology

2. Methodology

Figure 5 shows the overall methodology for the study. The data for the INPS system were obtained from various sources. Table 1 summarizes the data used for modelling the system along with their respective sources. The whole INPS system was simplified to a simple six-bus network based on various provinces in Nepal, as shown in Figure 6. Generators above 10 MW and transmission lines above 66 KV were only considered for analysis. Loads, generation, investment cost, and annual energy production within a province were aggregated. The load and generation parameters used in the analysis are shown in Table 2. The reactive power required by the load in each province was assumed to be fully compensated by reactive power sources located within the same province.

The total power that can be transmitted from one province to another was represented by a single transmission line. The maximum power that can be transmitted between provinces is presented in Table 3. Karnali Province was excluded from the study due to its relatively negligible generation and load demand compared to other provinces. Similarly, the Indian grid was not considered in the analysis. The simplified model based on the assumption was shown in Figure 6. The total generation, load, and transmission limit between different zones are shown in the figure.

The annual operational and maintenance costs for the generator were estimated from the initial investment cost from the Table 4 . The cost of production of energy per unit

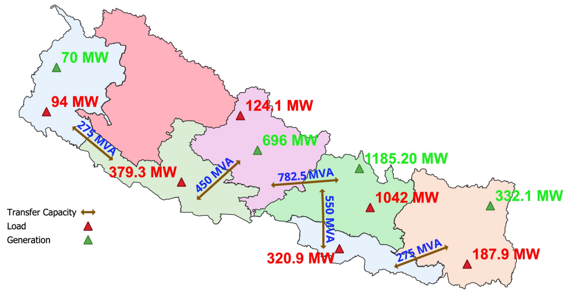

Figure 6. Simplified INPS System

was obtained by dividing the Operation and Maintenance (O & M) cost by Annual Energy Generation. Table 5 presents the (O & M) cost and the per-unit production cost.

Two different pricing schemes—uniform pricing and zonal pricing—were implemented in the developed model using PowerWorld Simulator. In the uniform pricing scheme, transmission line constraints were neglected, and a single market clearing price (MCP) was applied uniformly across all six buses. In contrast, the zonal pricing scheme accounted for transmission line constraints, resulting in different prices for each bus. The outcomes of both schemes were compared in terms of total generation cost, network losses, and consumer surplus.

3. Results and Discussion

The result for the uniform and zonal pricing scheme is presented in this section.

The supply and demand curve for the uniform pricing scheme is shown in Figure 7. The offer presented by the generation is represented with the supply curve, and

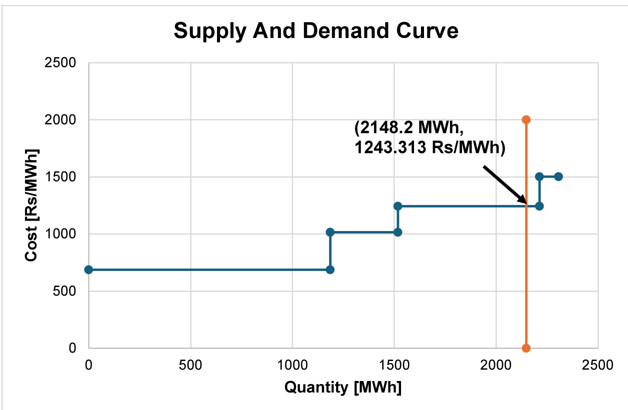

Figure 7. Supply and Demand Curve for Uniform Pricing Scheme

Table 1. Data Required for Analysis

Input Data	**Source**
Plant Maximum Generation	DOED Report
Plant Initial Investment	Annual Reports of Hydropower Projects, National News
Annual Energy Production	Annual Reports of Hydropower Projects, National News
Plant Location	DOED Report
Load Demand	NEA Annual Report
Transmission Line Parameters	NEA Annual Report, RPGCL Report

Table 2. Province-wise Generation and Load Data

Province	Load (MW)	Generation (MW)	Annual Generation (MWh)	Investment Cost (Million Rs)
Bagmati	1042.0	1185.2	6,052,513	148,823
Gandaki	124.1	696.0	3,789,907.4	161,503
Koshi	187.9	332.1	1,724,688	58,418
Lumbini	379.3	–	–	–
Madhesh	320.9	–	–	–
Sudurpashchim	94.0	70.0	448,300	22,460

Table 3. Power Transfer Capacity between Provinces

From	To	Power Transfer Capacity (MVA)
Koshi	Madesh	275
Madesh	Bagmati	550
Bagmati	Gandaki	782.5
Gandaki	Lumbini	450
Lumbini	Sudurpashim	275

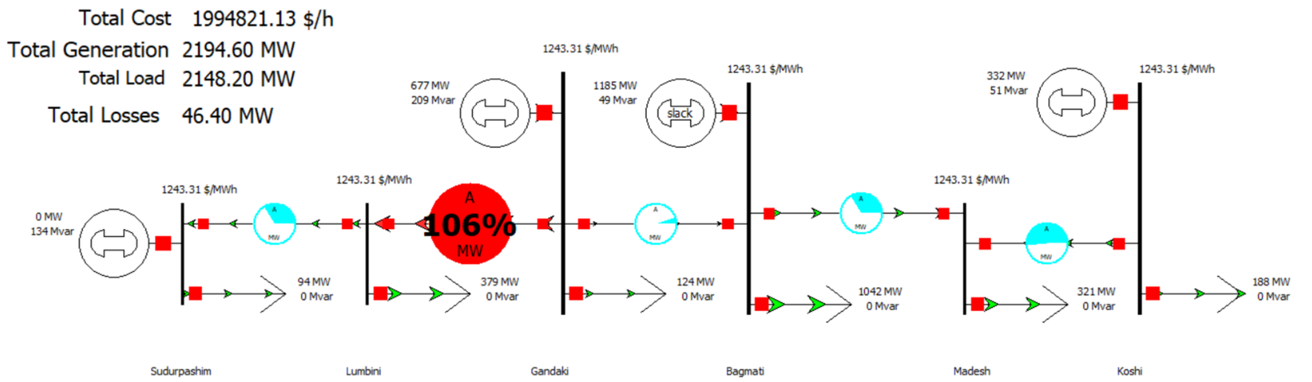

Figure 8. Uniform Pricing Scheme in Power World Simulator

aggregated inelastic load demand for the whole INPS system was represented by a load curve. The equilibrium point is given by the intersection of the supply and demand curves. The equilibrium price was obtained as 1243.313 Rs/MWh, and the equilibrium quantity was obtained as 2148.2 MWh. The generators whose offers are less than or equal to equilibrium prices are scheduled. The suppliers in the bidding zones Bagmati and Koshi are fully scheduled. The suppliers in Gandaki province are partially scheduled. The generators in the Sudurpashim Province are not scheduled. Table 6 shows the scheduled quantity, production price, and revenue and surplus for each supplier in uniform pricing scheme. The total cost of generation is found to be Rs 1994821.13.

Figure 8 shows the simulation model for the uniform pricing model in the Power World simulator. The result shows the existence of congestion between Lumbini and Gandaki Province. This congestion demonstrates that the solution derived from the uniform pricing model is not physically feasible, and generator redispatch is required to satisfy the line's capacity constraints.

Figure 9 presents the simulation model for the zonal

Table 4. O&M cost as a percentage of investment cost

Size of Hydro Power Plant	per cent of Initial Investment
less than 20 MW	4.00%
greater than 20 MW	3.00%
greater than100 MW	2.50%

Table 5. Cost Parameters

Province	O&M cost in million (Rs)	Annual Generation (MWh)	Per Unit Cost (Rs/MWh)
Bagmati	4162.35128	6052513	687.71
Gandaki	4712.04	3789907.4	1243.31
Koshi	1752.525	1724688	1016.14
Sudurpaschim	673.8	448300	1503.01

Table 6. Schedule Table for Uniform Pricing Scheme

Province	Cost (Rs/MWh))	Scheduled Quantily (MWh)	Production Cost (Rs)	Revenue (Rs)	Surplus (Rs)
Bagmati	687.71	1185.20	815069.51	1473574.57	658505.06
Koshi	1016.14	332.10	337460.09	412904.25	75444.15
Gandaki	1243.31	677.30	842095.89	842095.89	0.00
Sudurpashim	1503.01	0.00	0.00	0.00	0.00

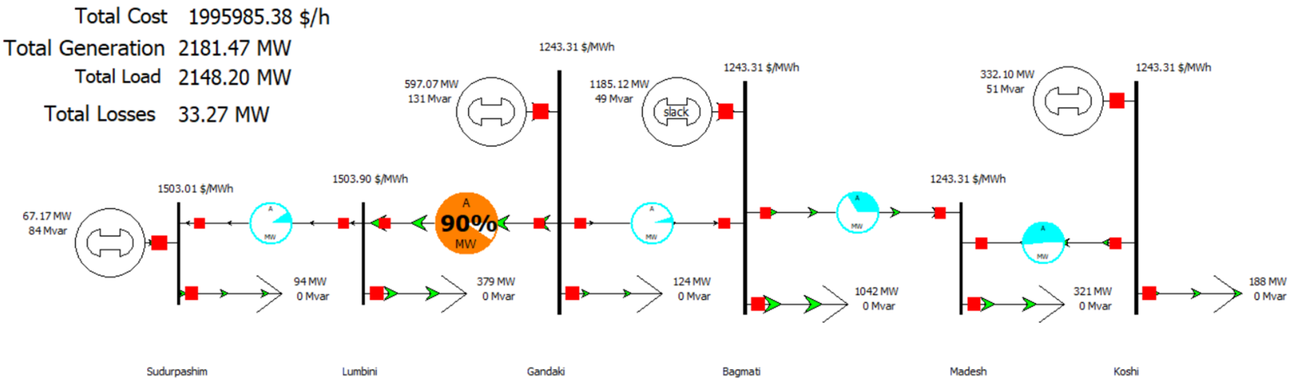

Figure 9. Zonal Pricing Scheme in Power World Simulator

Table 7. Schedule Table for Zonal Pricing Scheme

Province	Offer Price [Rs/MWh]	Scheduled Quantity (MWh)	Production Cost (Rs)	Bus Price [Rs/MWh]	Revenue [Rs]	Surplus [Rs]
Bagmati	687.7063	1185.12	815014.49	1243.31	1473475.10	658460.61
Koshi	1016.14	332.1	337460.09	1243.31	412904.25	75444.15
Gandaki	1243.313	597.07	742344.89	1243.31	742344.89	0.00
Sudurpashim	1503.011	67.17	100957.25	1503.01	100957.25	0.00

pricing scheme. In this model the network congestion is handled through redispatching. The generator in the Sudurpashim bidding zone was scheduled in order to satisfy the line's capacity constraint. Table 7 presents the scheduled quantity, production price, and revenue and surplus for each supplier for zonal pricing scheme. The total production cost in the zonal pricing scheme was found to be 1995985.38 Rs/hr. The increase in cost is accounted for by the scheduling of the highest-cost generator in Sudurpashim province. The losses in the network were decreased from 46.4 MW to 33.27 MW. The operation of the generator closer to the load center contributed to this reduction. The surplus to the supplier was slightly decreased to Rs 733904.76 per hour from Rs 733949.21 in the uniform pricing scheme.

4. Conclusion

In this study, a competitive wholesale electricity market model for Nepal has been developed. This model facilitates a comparative analysis of various pricing schemes and identifies the most suitable pricing mechanism that Nepal could adopt in the future. The model can be further improved by incorporating projected load growth, future generation sources, planned transmission infrastructure, and replacing inelastic load with price-sensitive loads. Additionally, it can be extended to simulate the reactive power market and assess market performance under contingency scenarios, such as the loss of low-cost generation. Overall, this study will support Nepal's ongoing electricity sector reforms.

5. Acknowledgment

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