IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received November 8, 2019, accepted December 1, 2019, date of publication December 9, 2019, date of current version December 23, 2019.

Digital Object Identifier 10.1109/ACCESS.2019.2958407

Cross-Border Power Trade and Grid Interconnection in SAARC Region: Technical Standardization and Power Pool Model

AZHAR UL-HAQ[1], MOHAMMAD SHAHMEER HASSAN[1], MARIUM JALAL[2,3], SHOAIB AHMAD[4], MUHAMMAD ALMAS ANJUM[1], IHSAN ULLAH KHALIL[1], AND ASAD WAQAR[5]

[1]NUST College of E&ME, National University of Sciences and Technology, Rawalpindi 44000, Pakistan
[2]Department of Electronic Engineering, Fatima Jinnah Women University, Rawalpindi 46000, Pakistan
[3]Department of Electrical Engineering, Lahore College for Women University, Lahore 54000, Pakistan
[4]SAARC Energy Centre, Islamabad 44000, Pakistan
[5]Department of Electrical Engineering, Bahria University, Islamabad 44000, Pakistan

Corresponding author: Azhar Ul-Haq (azhar.ulhaq@ceme.nust.edu.pk)

This work was supported in part by the National University of Sciences & Technology, College of Electrical and Mechanical Engineering, Rawalpindi.

ABSTRACT Cross-border power trading through grid interconnection has gained significant attention in South Asia to support energy deficit states of the South Asian Association for Regional Cooperation (SAARC) region. Nonetheless, cross border grid interconnection requires technical standardization and grid code synchronization to ensure technically feasible, reliable, safe and economical power exchange among the SAARC states. Importantly, grid code harmonization necessitates the uniformity of technical data and codes among the member states. In this paper, we investigate the relevant factors such as regional barriers, trade potential, a gap in the grid codes, standardization of technical data, energy pricing, load profile, the load factor of different states, and regulatory framework of different states. All these factors are found to be helpful in formulating a set of recommendations for seamless power grid interconnections and power trading. We have developed a power pool model for the SAARC region with an objective to effectively realize the objectives of cross-border power trade in the region. The presented model takes account of transparency in market-clearing price, bidding of data, season-wise load profile, market volume, best case practices, institutional setup and rigorous case studies to ensure seamless grid interconnection and reliable power trading within the region.

INDEX TERMS Cross-border power trade, standardization of technical data, grid code harmonization, power pool model.

I. INTRODUCTION

SAARC region has a population of 1.7 billion, which is nearly one-quarter of the whole world's population. The region has been confronted with a significant energy deficit. The two main factors, which contribute to energy shortages, are insufficient power generation resources in the SAARC states and their increased reliance on imported fossil fuel energy products for power generation. Framework agreement for electrical energy cooperation was signed by all SAARC member states including India, Pakistan, Nepal, Afghanistan, Sri Lanka, Bangladesh, Maldives, and Bhutan on 27th November 2014 at the occasion of SAARC conference held in Katmandu, Nepal. The key clause of the framework agreement includes a great emphasis on cross border trade of electric power, the legislation of rules and relevant laws, and support mechanism for bilateral and trilateral agreements among the SAARC member states (SMSs) [1]. The cross-border power interconnection facility permits electrical power to be exchanged between two or more countries [2]. The main objective of the agreement is to increase economic cooperation through new opportunities in the electrical energy sector with an expectation of optimal utilization of available power generation resources with increased reliability of electric power supply.

The power generation capacity of SMSs differs significantly. India, Pakistan, Nepal, Afghanistan, Sri Lanka, Bangladesh, Bhutan, and Maldives have their power generation capacity of 277,710 MW, 23,087 MW, 800 MW, 840 MW, 3940 MW, 11,877 MW, 1488 MW, and 140 MW

The associate editor coordinating the review of this manuscript and approving it for publication was Pierluigi Siano.

respectively [2]–[8]. Maldives' power generation is highly reliant upon fossil fuels while Bhutan and Nepal's power need is fulfilled through hydel resources [2]. Natural gas is a primary source to generate electricity for Bangladesh while coal is extensively burnt for electrical power generation in India [3]. Pakistan is not dependent on any single source for power generation and fulfills its electrical energy requirements from various sources [4]. Consequently, almost all the SAARC member states experience energy shortages either in summer or winter [5].

Regulatory authorities which are controlling power trade activities in SMSs are as follows: Da Afghanistan Breshna Sherkat (DABS) is responsible for electricity Generation, Transmission, and Distribution [6]. Indian electrical regulatory authority defines the roles and responsibilities of Regional Load Dispatch Centers (RLDCs). Unlike other countries, Maldives does not have dedicated power regulatory authority, rather it has just defined country-specific grid code which is not in line with that of other SAARC member states [7]. In the case of Nepal, Nepal Electricity Authority (NEA) is responsible for purchasing power from the private sector and importing power from India. NEA Grid code 2005 has well-defined standard formats for data and information exchange for power generation and transmission. Authority for issuing licenses for power transmission and distribution in Pakistan is National Electric Power Regulatory Authority (NEPRA), [8] but transmission line construction, operation, load dispatch, and maintenance come under the jurisdiction of National Transmission & Dispatch Company (NTDC). Similarly, the Ceylon Electricity Board (CEB) in Sri Lanka is responsible for electricity generation, transmission, and distribution [9].

It is an undoubted fact that the power grid code of all SMSs need to be harmonized to ensure seamless cross-border power trade because any differences between grid codes of the states may cause technical in-compatibility in achieving the true purpose of power exchange. Cross border power trade in the SAARC region can effectively be realized through a resolution of relevant barriers. These barriers include an absence of cost-reflective pricing, under-performing financial utilities, persistent generation capacity shortages, lack of private sector involvement, political relations and cross border power trade regulations. The stakeholders of SAARC states know the aforementioned issues but no significant efforts are witnessed to address them. Importantly, the exchange of data and information is a prerequisite for the physical exchange of electricity and electricity services among industry participants. It is found that electricity exporting and importing member states must share technical data on generation and transmission aspects associated with the cross-border trade of power.

Currently, a few SMSs are engaged in power trading outside the SAARC region such as Afghanistan fulfills its electricity need by importing it from Tajikistan, Uzbekistan, Turkmenistan, and Iran. Transmission lines from Uzbekistan, Iran, Tajikistan, and Turkmenistan have a power carrying capacity of 326 MW, 164 MW, 433 MW, and 77 MW respectively [7]. Construction of 500 kV CASA transmission lines between Nowshera, Pakistan, and Sangtuda in Tajikistan through Torkham in Afghanistan commenced back in May 2016 [10]. India and Bangladesh have a bilateral electricity trade agreement, which was signed between the two countries under which NTPC Vidyut Nigam (NVNN) becomes the nodal agency for electricity trade with Bangladesh. India and Nepal have a Bilateral agreement under which Nepal imports power from India. Iran exports 39 MW to the Baluchistan province of Pakistan through a radial mode transmission system [11].

To ensure effective cross-border power trade among SMSs, it is believed that there must be a model that shall be followed to unify member states onto a single electricity market. This paper presents a South Asian Regional Power Pool, a power trading model, which not only serves the unification but also brings a transparent electricity pricing scheme for cross border power trade. A few best-case practices of regional power pool models are also elaborated to reinforce the importance of cross border power trade in the SAARC region.

In addition, the electrical load pattern in SMSs is also covered in detail with the description of load profile and load factors of the member states in different seasons, which help determine suitable scenarios of power exchange among the various member states [12]. According to a typical load profile and load factors of a member state, appropriate recommendations are given for the season-wise exchange of power.

This paper consists of ten sections, the first section gives an introduction, the second section presents an overview of the energy mix of SMSs, and the third section highlights the importance of harmonization of grid codes for cross border power trade. Barriers for cross border power trade are discussed in detail in Sec. IV. Sec. V contains detailed information on the minimum standardized format of data to enable the power trading functional in the SAARC region. The sixth section of the paper discusses the current situation of power trade among SAARC states. The seventh section elaborates on the power trading model and best case practices. Case studies related to power pool models are detailed in Sec. VIII. Load scenarios with seasonal load factors of SMSs are covered in Sec. IX and eventually the paper is concluded in Sec. X.

II. ELECTRICAL ENERGY SCENARIO OF SAARC MEMBER STATES

The SMSs have been striving to become power surplus but so far only two states including Bhutan and Maldives have managed to achieve this milestone. Bhutan stands at an outstanding power export figure of 628.74 MW in the summer season which drastically drops down in winter due to unfavorable winter season for hydro-electric power generation. Bhutan manages to fulfill its power needs by 90% and the rest is catered through the import from India.

Maldives produces enough electricity to fulfill its power requirements by generating 45.89 MW. Fig. 2 gives a

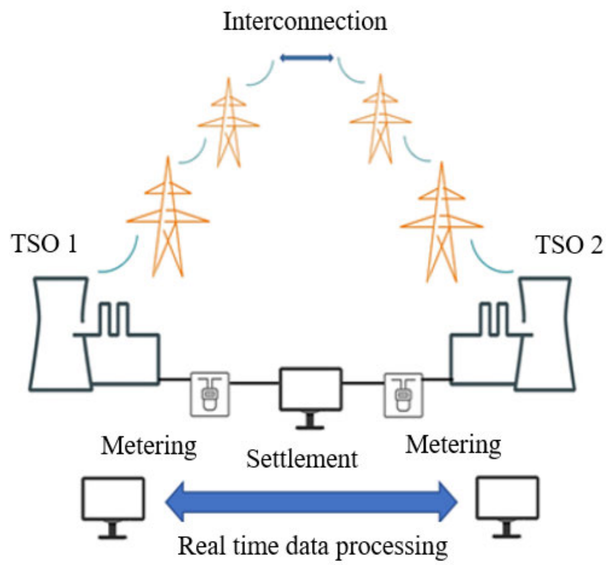


FIGURE 1. Cross-border interconnection facility.

status of power generation, demand, and energy deficit of SMSs, which shows that the other six member states are far from achieving the objective of meeting their energy demand [13]. Table 1 contains an energy mix of each country [17]–[26].

There is no doubt about the diversification of energy sources in SAARC as shown from the statistics given in Table 1. However, numerous factors are still propelling SMSs towards energy deficiency. These factors are resource underutilization, limited focus on renewable energy sources, extraordinary reliance on conventional energy sources and most importantly lack of regional power trade [14].

Considerable utilization of coal reserves in India has already caused serious environmental concerns. Bangladesh and Pakistan fulfill their power needs by importing fossil fuel from different parts of the world.

On the other hand, renewable energy (RE) sources are abundantly available in the SAARC region, which has not been tapped to its potential at a larger scale. Recently, Pakistan, Afghanistan, and India have shown their resolve on increasing the proportion of renewable energies in their energy mix. At present, the overall percentage of the energy mix is around 1%. Sri Lanka is the only state to have a significant contribution to renewable energy resources amounting to 12% towards their total energy mix. It is recognized that the energy mix of every member state must be diversified to bring improvement in environmental pollution and sustainability in terms of longevity and cost.

III. GRID CODE SYNCHRONIZATION AMONG SAARC STATES

Grid code lays the foundation for carrying out cross-border power trade between countries. Power trade is only possible once grid codes of countries are synchronized and we will see its importance in a relevant subsection later. The primary purpose of grid code is to convey technical information related to transmission system operators, users, power system stakeholders' operational guidelines, rules, design criteria, and basic planning involved. Regulatory bodies are authorized to approving the grid code under the country's electricity legislation or act. Grid code documents also deal with the rules and criteria associated with ancillary services, selling or buying power, maintenance, metering, protection, distribution, transmission, generation, and system operation. Existing gaps in the grid code of SMSs are identified and discussed below.

A. NECESSITY FOR HARMONIZATION OF GRID CODE

A framework must be established by the transmission system operators (TSOs) of planned regional grid interconnection for electricity market mechanisms, exchange of power, settlement of disputes, data exchange, schedules for maintenance, operating procedures, guidelines preparation, and implementation. The status of the grid code document and the concerned regulatory bodies in SMSs are shown in Table 4.

There are discrepancies in the permissible range of voltage, frequency and transient stability as specified by the grid code of the member states. These differences must be eradicated to ensure the smooth operation of the interconnected systems [15]. The operating system frequency in all member states is 50Hz but the difference lies in their permissible deviation range as shown in Table 2. The operating frequency band of Afghanistan is not specified as they have it has no grid code defined yet.

Transmission voltage level also differs significantly in the SMSs, which poses a technical issue regarding voltage stability in a cross-border interconnected power system. The differences in voltage levels are highlighted in Table 3.

Transient stability limits defined by grid codes of some SMSs varies at different voltage levels. Cross border power trade is only possible if these differences are addressed otherwise fault clearing time difference between member states will render interconnected power system inoperable. The Bangladesh grid code mentions that fault clearance time shall not exceed 100ms at 400kV and 160ms for both 220kV and 132kV. The grid code of Bhutan does not dictate any specific fault clearance time limit. Similarly, the Nepal grid code didn't mention any transient stability limits. Among all member states, the Indian grid code covers transient stability limits in detail as it mentions fault clearance time by considering fault types and voltage levels. For a three-phase to ground fault, the Indian grid code states that fault must be cleared within 100ms at 765kV and 400kV, and within 160ms at 220kV and 132kV. As per the grid code of Pakistan, three-phase to ground fault must be cleared within 100ms at a voltage level of 500kV and 220kV. Remaining member states have not incorporated transient stability parameters in the grid code.

Fig 4. depicts the grid code and its associated sub-codes for seamless cross border electricity trading among the SAARC member states.

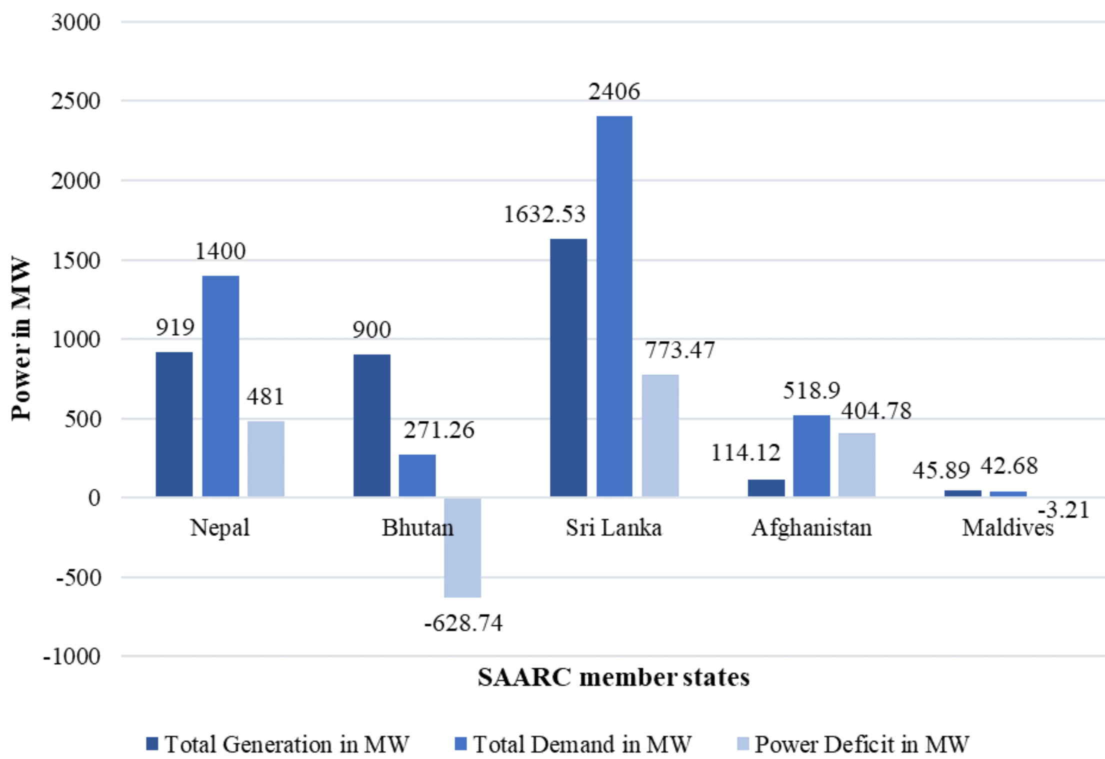


FIGURE 2. Electrical energy scenario in SAARC member states.

TABLE 1. Energy mix OF SAARC member states [16]–[23].

SAARC Member State	Hydro-electric power	Oil	Coal	Thermal energy	Natural gas	Biofuel and Waste	Nuclear Energy	Renewable Energy
Bhutan	99%	1%	-	-	-	-	-	-
Nepal	93%	-	-	6.9%	-	-	-	0.1%
Bangladesh	57%	17%	3%	-	-	22.9%	-	0.1%
India	0.09%	5.48%	80.35%	-	12.74%	-	-	1.34%
Sri Lanka	35%	15%	22%	16%	-	-	-	12%
Maldives	-	97%	-	-	3%	-	-	-
Pakistan	29%	35.2%	-	-	29%	-	5.9%	-
Afghanistan	2%	56%	29%	-	4%	9%	-	-

TABLE 2. Permissible frequency range of SAARC states.

S.No.	Member State	Frequency (Hz)
1	Afghanistan	NA
2	Bangladesh	49.0-51.0
3	Bhutan	49.5-50.5
4	India	49.9-50.05
5	Maldives	49.5-50.5
6	Nepal	48.75-51.5
7	Sri Lanka	49.5-50.5
8	Pakistan	49.5-50.5

i. Planning Code is responsible for the provision of details associated with information supply and criteria for planning and development procedures.

ii. Connection Code sets a benchmark for operational plant design, and techniques, which should be compiled in view of the prospective consumers.

iii. Operation Code includes information about the operating procedures including data provision, operational planning and demand-side management, and control.

iv. Schedule and Dispatch Code contains the procedures of power generation, dispatch, and scheduling.

v. Metering Code addresses the information related to meters, meters accessibility, accuracy level, and standards compliance of metering.

1) N-1 CONTINGENCY CRITERIA FOR AC LINES

It is one of the gaps among SMSs because, in India, outage of a single circuit at 400 kV and 765 kV levels and outage of a double circuit at 132 kV and 220 kV levels is considered as N-1 outage [24].

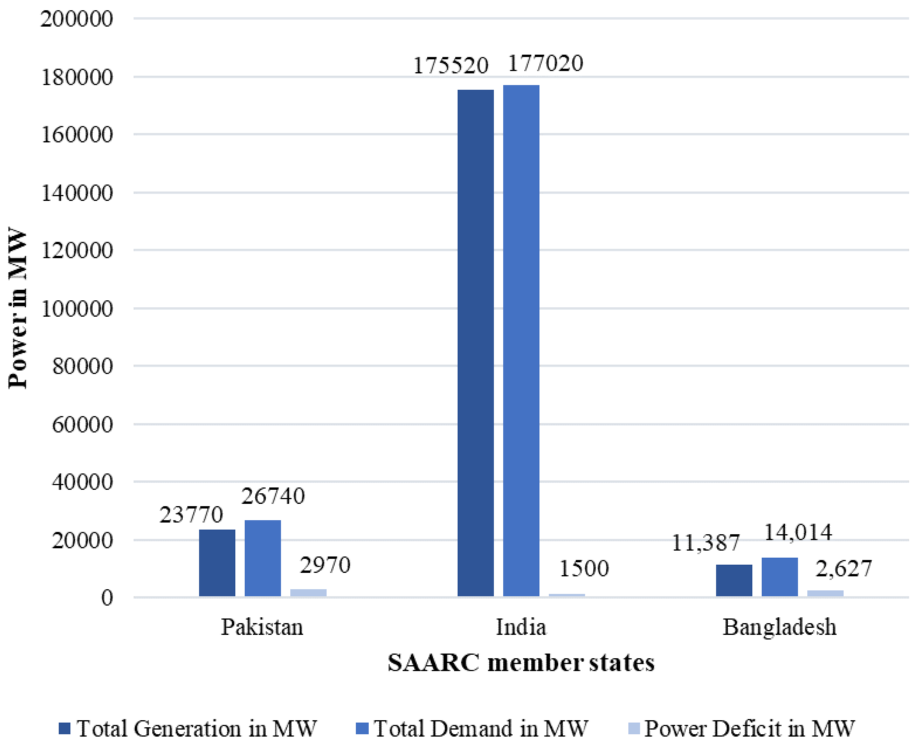


FIGURE 3. Power demand state of SMSs [17]–[26].

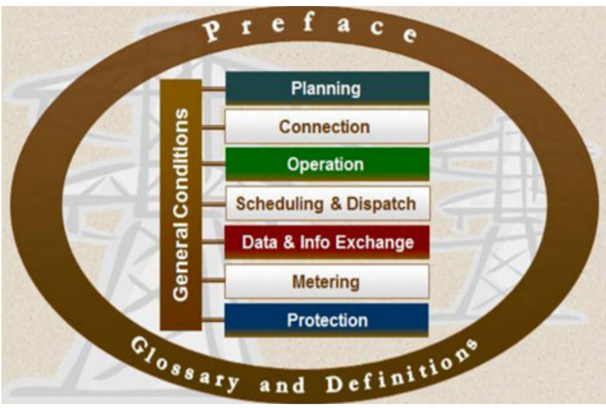


FIGURE 4. Composition of grid code.

2) N-1 CONTINGENCY CRITERIA FOR HVDC

Among all SMSs, only India has HVDC back-to-back station with defined N-1 contingency criteria [24]. Whereas, other states don't have such standards defined.

3) DYNAMIC STABILITY

This gap persists in all SMSs. Bangladesh, India, and Pakistan specify that the system shall survive a permanent three-phase to ground fault on EHV lines with a fault clearance time of 100ms. Indian grid code specifies many other disturbances also in detail for ensuring system stability [25]. Other states need to specify this code.

4) LOSS OF SINGLE GENERATOR

Grid codes of India and Sri Lanka stipulate that the grid system shall survive any loss of a single generator. However, grid codes of other member states do not specify any such criterion.

5) VOLTAGE VARIATIONS

Except for India, the grid code of all SMSs specifies voltage variation limits for both planning and operational phases [25].

6) SECURITY AND RELIABILITY LIMITS

In the case of India, the transmission planning criteria, as devised by Central Electricity Authority (CEA), specifies security and reliability limits to be considered at the planning stage, which is more stringent than the operational security and reliability limits. A margin is specified for voltage limits, thermal loading limits of lines and transformers, reactive power capabilities of generators, fault levels, etc. The grid code of other SMSs mentions operational security limits only [25].

IV. BARRIERS TO CROSS BORDER POWER TRADE IN SAARC REGION

SAARC region experiences considerable under-utilization of cross border power trade despite its huge potential for the power exchange. Though diverse sources of energy are available, several factors offer hindrance in cross border power trade amongst SMS. This section identifies those factors and elaborates on how they contribute to restricted power exchange amongst the SMSs.

The electricity policy reforms (EPR) amongst SMSs are mainly focused on improvement in operation rather than the introduction of market-oriented policies except for India.

TABLE 3. Permissible tranmission voltage range of SMSs.

S.No.	Member State	HVAC Transmission Voltage levels (kV)	Voltage range
1	Afghanistan	220 110	NA
2	Bangladesh	400 230 132	+/- 5%
3	Bhutan	400 220 132 66	+/- 5%
4	India	765 400 220 132 110 66	728-800 kV 380-420 kV 198-245 kV 122-145 kV 99-121 kV 60-72 kV
5	Maldives	11 33	+/- 10%
6	Nepal	132 66	+/- 10%
7	Sri Lanka	220 132	+/- 10% +/- 5%
8	Pakistan	500 220 132 66	+/- 10%

In India, there is competition in the electricity wholesale market and day-ahead market while the other member states are still adhering to the single-buyer model in which there are only one buyer and multiple sellers. The critical issues associated with electricity regulation in the SAARC region are as follows:

A. ABSENCE OF COST REFLECTIVE PRICING

There is no proper pricing scheme in effect that helps the power sector to reap financial benefits. As a result, it has been observed that there has been limited investment in improving the efficiency of operations and increasing installed capacity. Moreover, it also dents the confidence of the private sector in a generation.

B. UNDERPERFORMING FINANCIAL UTILITIES

The scarcity of revenue remains one of the major problems of stakeholders within the SAARC region. The considerable part of this scarcity is contributed by electricity theft. In India, almost one-third of electricity is lost as a result of theft and it is estimated that there is 14% theft in Bangladesh [1]. Additionally, "circular debt" is also contributing towards shortfall of revenue. Circular debt is considered a barrier in achieving the desired outcome which propels entities to hold payments of their creditors and suppliers, and thus, it creates difficulties for them to meet their expenses.

C. PERSISTENT GENERATION CAPACITY SHORTAGES

There is a wide gap in investment and growing demand in the power sector which results in frequent power outages. For example, some rural areas of Pakistan are still experiencing load shedding of 8 to 12 hours a day. In Nepal, the daily blackouts have ended in 2016 as a result of cross border power trade with India. Thus, an immense economic loss is experienced as a result of power outages in SAARC member states.

D. LACK OF PRIVATE SECTOR INVOLVEMENT

In the SAARC region, privatization of the existing electrical distribution system remains a political issue. Though privatization would yield better results, it is prone to political hurdles. Despite, private distribution companies are generally able to bring a significant reduction in commercial and technical power losses [26].

E. CROSS BORDER RELATIONS

In general, SMSs have a fair level of political understanding which may contribute to electrical cooperation among them e.g. Bhutan-India cooperation is a prime example of sharing mutual interests [1]. On the other hand, cross border power trade is much restricted owing to political sovereignty, national security and energy security in the case of Pakistan and India. These two member states have animosity and trust deficit among themselves. Similarly, the failure of supplying natural gas for a 3 billion USD power project in Bangladesh is another example of their limited capabilities [1]. In addition, it is still questionable whether the social impact, and public concerns would be addressed by cross border electricity or not? as the sharing of water resources between Nepal and Bhutan causes conflicts of extra revenue generation between the two states.

F. CROSS BORDER POWER TRADE REGULATION

To encourage cross border power trade within a region, it is considered necessary that system operators shall focus on the implementation of harmonized regulatory and technical practices. To ensure effective power trade, tracking of power flows, maintenance of grid, attracting investment in grid interconnection, and collection and transfer of revenues are must be enhanced considerably. Current coordination issues among SMSs are mostly policy-based e.g. rules associated with transmission access along with its pricing that does affect the market access and dispute resolving. This issue

TABLE 4. Grid code and electricity market regulator in SMSs [5]–[9].

S.No.	Member State	Grid Code	Ultimate Legal Document	Electricity Sector Regulator
1	Afghanistan	Not Available* (NA)	Not Available* (NA)	Not Available* (NA)
2	Bangladesh	Grid Code, 2012	Electricity Act 2003 (Amendments 2005 and 2010)	Bangladesh Energy Regulatory Commission (BERC)
3	Bhutan	Grid Code 2008 (Reprint 2011)	Electricity Act of Bhutan, 2001	Bhutan Electricity Authority (BEA)
4	India	Grid Code 2010 (Amendment 2014)	Electricity Act, 2003	Central Electricity Regulatory Commission (CERC), State Electricity Regulatory Commissions (SERC) for each state
5	Maldives	NA	NA	Maldives Energy Authority
6	Nepal	Grid code 2005 (Draft)	Electricity Act 1992	Department of Electricity Development
7	Pakistan	Grid Code, 2005	NEPRA Act No. XL of 1997	National Electric Power Regulatory Authority (NEPRA)
8	Sri Lanka	Grid Code, 2014	Electricity Act 2009	Public Utilities Commission (PUC)

is reflected in the slow response of India in its power trade agreement with Nepal [1].

G. CAPITAL AND OPERATIONAL COST OF CROSS BORDER TRANSMISSION NETWORK

Capital and operational cost associated with cross border transmission lines are one of the major hurdles in carrying out power trade in the SAARC region. However, it may be considered a long-term investment and its benefits shall be reaped in terms of a reduced bill of the imported energy for the purpose of power generation. Thus, it will ultimately offer financial relief to consumers. In this regard, Asian Development Bank has conducted a cost-benefit analysis of cross border power interconnection in the SAARC region as given in [27]. The proposed network includes: additional grid reinforcement for Bhutan and India grid; 400 kV line connecting India and Nepal; HVDC link between India and Sri Lanka, which also includes submarine cable; HVDC direct link of India and Bangladesh; 400 kV and 220 kV transmission link between in India and Pakistan; and 400 kV transmission link of India and Pakistan, which is also coupled with CASA 1000 transmission line.

Transmission networks mentioned above have a varying capacity from 250 MW to 1000 MW. The cost-benefit analysis presented in [27] shows that the ratio of cost to benefit ranges from 3.7 to 102 with an overall profit of around 105 million USD to 1840 million USD.

V. MINIMUM SET OF STANDARDIZED DATA

SMSs need to consider a variety of regulatory and technical barriers in the power trade. Defining a minimum standardized set of data and information exchange helps in tackling these technical limitations, standard interfaces and, resolve to overcome energy deficit [25].

A. DATA EXCHANGE BETWEEN OPERATORS AND CROSS BORDER LINKS OBSERVABLE AREA

Transmission or Distribution licensee shall carry out grid interconnection study to determine the point of interconnection, required interconnection facilities and modifications required on the existing grids to accommodate the interconnection. The study may also address the transmission system capability, transient stability, voltage stability, losses, voltage regulation, harmonics, voltage flicker, electromagnetic transients, machine dynamics, Ferro resonance, metering requirements, protective relaying, substation grounding, and fault duties, as the case may be.

General composition of information may be as follows:

i. Regular substation topology and other data based on a voltage leve

ii. Maximum and minimum active and reactive power, which is required for power modules.
iii. Operational security limit
iv. Voltage regulation range
v. Configuration of a transmission system of 400kV
vi. Protection set points as external contingencies in neighboring operato's contingency lists.

Data for dynamic stability analysis must include:

i. Electrical parameters associated with alternators suitable for analysis of dynamic stability.
ii. Minimum reactive power and maximum reactive power.
iii. Prime mover and excitation system models that may withstand larger disturbances.

Real-time flow of information among all operators includes:

i. System frequency.
ii. The error associated with frequency restoration control.
iii. The measured active power exchange between load areas.
iv. Power exchange which involves virtual tie-lines.
v. Actual topology of a substation.
vi. Regulating positions of transformer that includes phase-shifting transformers.
vii. A measured or estimated voltage of a busbar.
viii. Restrictions imposed on active and reactive power supply capabilities concerning the observable area.

The data provided to transmission network operators by distribution operators must be comprised of:

1) Structural information
2) Information on the lines that connect the sub-stations
3) Total aggregated generating capacity

B. DATA FOR POWER EXCHANGE

To have effective communication between the market operator and system operator, it is essential to have data format for registration in the market information system as given in Table 5, [29]–[33]. The data format for bid submission is also given in Table 6.

C. INSTITUTIONAL SET-UP

The institutional set-up must be comprised of the following:

i. Regional power trade committee for the approval process.
ii. Coordination committee (led by secretaries of ministries related to power) for coordination.
iii. A panel of experts for designing electricity market model, market operation rules, grid code, and relevant policies.
iv. Regional electricity regulation authority managing regional power trade committee, coordination committee and a panel of experts.
v. Regional level institute for utilities, market operators, buyers and sellers, traders, grid operators, etc.

A panel of experts shall propose viable electricity market and market operating guidelines where standard data shall be proposed and designed. For regional level planning, long term and short-term planning shall be shared among countries. These plans should be compiled by the regional regulatory authority and shared with stakeholders. Skilled personnel should be engaged in designing a standard format for the regional competitive power market. Necessary infrastructure and quality of infrastructures like dedicated internet, cybersecurity, and protection system shall be defined and developed accordingly. The role of regional system operator, national system operator, and transmission line operators shall be clearly defined. Communication shall be done between regional market operators, regional system operators, national system operators, and regional transmission line operators. Guideline/Policy of data and information exchange shall be defined. Standard format for exchanging data and information shall be developed with consensus and harmonized manner. Data designed by CERC in India are used for bilateral electricity trade. Such a format can be used to come up for the design of the practically oriented format as a first step.

VI. CURRENT POWER TRADE SCENARIO IN SOUTH ASIA

Power trading among SMSs has gained significant attention for a few years. There have been a few attempts by different states for power trade. The current scenario of cross-border power trade is depicted in Fig. 5 and is explained below.

A. INDIA AND BANGLADESH

A bilateral electricity trade agreement was signed between the two countries under which NTPC Vidyut Vyapar Nigam (NVNN) becomes the nodal agency for the bilateral trade of electricity. Bangladesh Power Distribution Board (BPDB) and NVNN signed a power purchase agreement for supplying 100 MW to BPDB. Initially, 175MW was supplied by India to Bangladesh back in September 2013. The first power grid connection was realized with a 400kV AC transmission system. The power trade has enabled Bangladesh to shift from its costly and less efficient fossil-fuel based power generation to import of electricity from India, which is quite economical.

B. INDIA AND BHUTAN

The government of Bhutan and India signed an inter-governmental agreement on 22 April 2014 to develop joint hydropower projects. The agreement provides a framework for the implementation of four hydroelectric plants (HEP) to produce a total power of 2120 MW. Three hydroelectric power plants are already functional in Bhutan with a power capacity of 1416 MW (1020MW Tala HEP, 336MW Chukha HEP, and 60MW Kurichhu HEP), and the produced power is being supplied to India. Furthermore, three HEP totaling 2940MW are under construction. Table 7 summarizes the joint venture between the two-member nations [39].

TABLE 5. Data format for registration in market information system.

S.No.	Supplier	Buyer	Electricity Trade	Electricity Transmission Company
1	Full name			
2	Short name			
3	Owner of the company			
4	Full address			
5	Contact: email and phone number			
6	Contact person (Full name designation, contact number and email)			
7	Country of company registration			
8	Company registration certificate			
9	Tax clearance			
10	Details of power plants	Details of industry/consumptions	-	Details of transmission lines
11	Nearest substation	Nearest substation	-	-
12	Location of metering	Location of metering	-	-
13	Bank details for transaction and guarantee	Bank details for transaction and guarantee	-	-

FIGURE 5. Power trade among SAARC countries.

C. INDIA AND NEPAL

An agreement between the two states was signed under which Nepal imports power from India. The agreement stresses the cooperation of the two parties to ensure reliable and secure grid operations that are interconnected via cross border transmission network. It includes unscheduled interchange, cross-border power trade procedures, bill accounting, energy metering, dispatch, and preparation of scheduled generation. In addition, it does state that all parties should put their maximum efforts to ensure greater reliability, stable operation, power system security, and safety requirements of the power grid [40].

TABLE 6. Data format for bidding.

S.No.	Bidding by Supplier	Bidding by Buyer	Bid Reception Confirmation by Market Operator	Bid Matching	Financial Settlement
1	Code number of supply bid	Code number of Buying Bid	Name of Buyer or Supplier	Total Number of Participants	Name of Buyer or Supplier
2	Location of bid submission	Location of bid submission	Purchasing code or Selling Code	List of Matched Bids (selling and buying	Purchasing code or Selling Code
3	Name of Bid Submitter, Designation, Contact No. and Email	Name and ID of Buyer	Declared Maximum Buying Capacity or Selling MWh	Volume of Matched Electricity Demand and Supply	Volume of Transacted Electricity Trade
4	Verifications	Name of Bid Submitter, Designation, Contact No. and Email	Electricity Buying or selling Quantity	Matching Available best tariff	Rate offered for Transacted Electricity per unit
5	Power Plant Information	Verifications	Rate offered for Buying or selling Electricity per unit	Total Amount of Transaction	Total Volume of Transacted electricity
6	Declared Maximum Generation Capacity MWh	Use of Power	Time of Bid Submission		Total Amount of Transaction
7	Electricity Supply Quantity	Declared Maximum Buying Capacity MWh	Location of Bid Submission		Recommendation of bank Transfer
8	Cost of Electricity per unit	Electricity Buying Quantity			
9	Bank details	Price of Electricity per unit			
10		Bank details			

TABLE 7. Joint venture for power production between India and Bhutan.

S.No.	Hydro Electric Project	Capacity	JV Partners
1	Kholongchu HEP	600 MW	SJVN Ltd. of India and Druk Green Power Corporation (DGPC) of Bhutan (50:50 JV, 70:30 DER
2	Bunakha HEP (with 230 MW downstream benefit from Tala, Chukha and Wangchu HEPs	180 MW	THDC Ltd. of India and Druk Green Power Corporation (DGPC) of Bhutan (50:50 JV, 70:30 DER)
3	Wangchu HEP	570 MW	SJVN Ltd. of India and Druk Green Power Corporation (DGPC) of Bhutan (50:50 JV, 70:30 DER)
4	Chamkarchu HEP	770 MW	NHPC Ltd. of India Druk Green Power Corporation (DGPC) of Bhutan (50:50 JV, 70:30 DER)

D. CENTRAL ASIA AND AFGHANISTAN

Afghanistan fulfills its electricity needs by importing it from Tajikistan, Uzbekistan, Turkmenistan, and Iran. The transmission lines from Uzbekistan, Iran, Tajikistan, and Turkmenistan have a power carrying capacity of 326MW, 164MW, 433MW, and 77MW respectively. Since the power grid of Afghanistan is not technically synchronized with the countries from which it imports power, thus it faces higher costs of grid interconnection and reduced reliability of power supply [17]. Construction of 500 kV, under

CASA 1000 project, transmission line between Nowshehra in Pakistan and Sangtuda in Tajikistan through Torkham in Afghanistan commenced back in May 2016. Later Afghanistan announced to abandon 300MW shares of energy imports under the CASA 1000 project due to a decrease in their power demand. However, Pakistan gets benefited by this decision as it is set to be supplied with 1300 MW power under the project [17].

E. IRAN AND PAKISTAN

An agreement was signed between Pakistan and Iran in 2002 to start the power trade. Iran exports electricity which is used in the Baluchistan province of Pakistan. As per the agreement, Pakistan can import 39 MW through a radial mode transmission system. In 2006, the two countries signed another MOU to increase electricity trade up to 100 MW to meet the power demand of Gwadar port [1]. Currently, Pakistan is importing 74 MW for its Baluchistan province. A few more projects in progress are aimed at power exchange of 1000 MW through 500 kV HVDC lines.

VII. PROPOSED POWER TRADING MODEL IN SAARC REGION

SAARC Regional Power Pool Model (SAARP) is proposed to ensure smooth coordination among SMSs for developing a unified regional electricity market. In this section, a set of objectives is defined for the effective functioning of a unified market of the SAARC region, which is as follows:

1- Introducing competition and market evolution procedure for demand and supply of electricity.
2- To encourage deployment of advance technology for increased efficiency of generation, transmission, and distribution of electricity.
3- To devise mathematical modeling of pricing scheme.

It is assumed that all SMSs will have a similar set of procedures for granting license of cross border power exchange. It is expected that SMSs will be engaging in the proposed power trading model as it sets a benchmark for power pricing and brings other ease of business.

A. FORMULATION OF MARKET CLEARING PRICE AND MARKET CLEARING VOLUME

Market clearing price (MCP) is defined as the lowest price at the point of intersection of supply and demand curves. Market clearing volume (MCV) is the volume of power at the point of intersection. Two types of markets exist based on a bidding mechanism. Single side bidding which is defined as bidding carried out by the supplier only, whereas double-sided bidding is bidding being accomplished by both customers as well as suppliers [44]. In our case, we have only considered linear demand and supply curves. It is because of the linear trend, bidders will be receiving power based on incremental and decremented cost curves [45]. Bidders can also bid their outputs in the linear form as shown in Fig. 7. In the case of single-side bidding, the function of MCP for any bidder n can be represented by using Eq. (1)

$$Q_n(p) = \frac{p}{msi} \tag{1}$$

where $\boldsymbol{msi}$ is a gradient of the supply curve and it is shown in Fig. 6. $\boldsymbol{Q_n}$ ($\boldsymbol{p}$) is the quantity associated with $\boldsymbol{n}$ th supply curve and $\boldsymbol{p}$ is the price in cents per kWh. If there are $\boldsymbol{N}$ number of suppliers who are bidding in market then the function of MCP for the combined supply curve is represented using Eq. (2)

$$Q_n(p) = p\sum_{i=1}^{N}\frac{1}{msi} \tag{2}$$

The MCP for a fixed demand D can be obtained by Eq. (3)

$$MCP = \frac{D}{\sum_{i=1}^{N}\frac{1}{msi}} \tag{3}$$

In the case of single side bidding, demand bid is inelastic however in double side market the elasticity of demand curve has also been taken into account. For MCP, both supply and demand ends are considered for its computation. The demand curve for an individual n in a linear bid mode can be found using Eq. (4)

$$D_n(p) = \frac{p_{io} - p}{mdi} \tag{4}$$

where mdi is a gradient of the demand curve and p_{i0} is the y-intercept or interception at price axis and it is shown in Fig. 6. If there are M number of demand bidders who are bidding in market then the expression for aggregated demand curve would be calculated using Eq. (5)

$$D(p) = \sum_{i=1}^{M}\frac{p_{io}}{mdi} - p\sum_{i=1}^{M}\frac{1}{mdi} \tag{5}$$

The MCP for a fixed demand D can be obtained by Eq. (6)

$$MCP = \frac{\sum_{i=1}^{M}\frac{p_{io}}{mdi}}{\sum_{i=1}^{M}\frac{1}{msi} + \frac{1}{mdi}} \tag{6}$$

If capacity limit is specified then we can write Eq. (1) in the form of Eq. (7) below and Eq. (2) can be written in the form of Eq. (8).

B. SAARC REGIONAL POWER POOL MODEL (SARPP)

SAARC Regional Power Pool Model (SARPP) is proposed considering a transparent pricing scheme for power trading, and congestion management in the region. Fig. 7 depicts a theoretical model of power pool involving relevant stakeholders in the market. In this model, a competitive electricity market concept is embraced where participants are expected to submit hourly bids on Day-Ahead (DA) basis. Characterization of power exchange (PX) is done hourly by cleared physical delivery market and it should have a uniform price having an option of linear bidding. The existing power

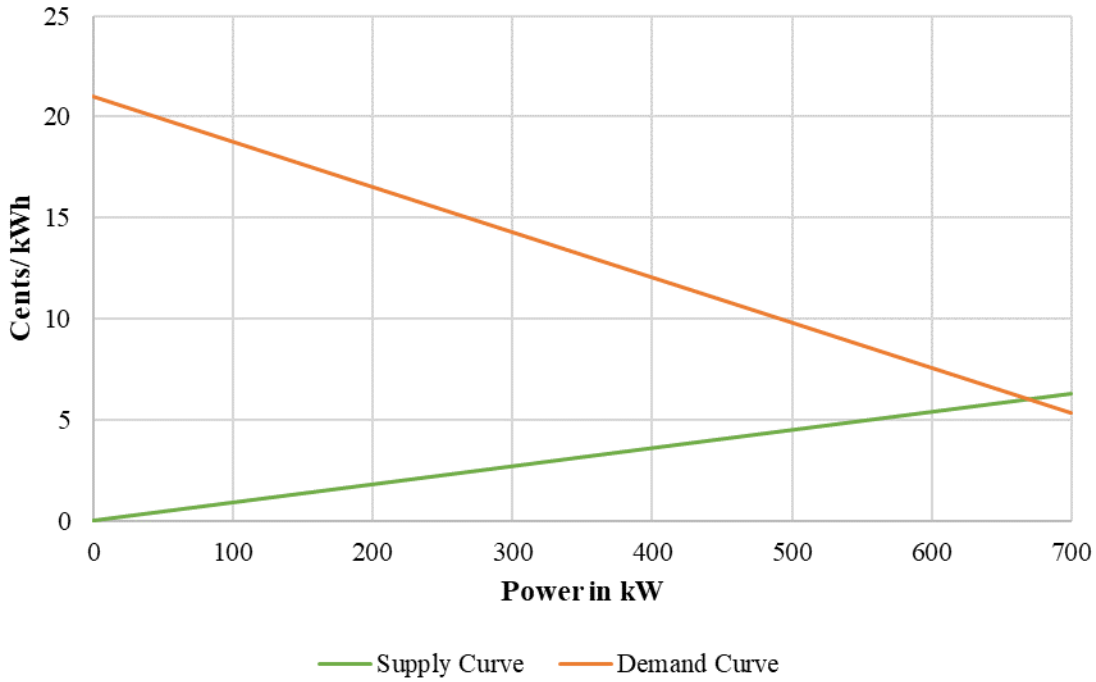


FIGURE 6. Aggregate supply and demand plot.

purchase agreements would be honored which means that PX should be a secondary option for the market to match unallocated surplus power through the DA auction-based market. The financial flows as a result of power trade are termed as 'commercial transactions' while electricity trade is referred to as 'physical transaction'. The participants will submit their electronic bids offering PX and in return, PX will clear the market through the determination of market clearing price (MCP), as shown in Fig. 6. If congestion is being caused by market settlement then splitting of the market is accomplished by PX and area wise MCP is determined with transmission constraints. Independent system operator (ISO) and transmission system operator (TSO) on DA basis will provide available transmission capacity (ATC) information to PX for congestion management and prepares the finalized DA schedule to clear the transactions. It is where PX shall submit this schedule to ISO for its real-time implementation. For the next day in between 00:00 and 24:00 hours, the electricity will be provided and financial clearing should be done once a week. The decentralized power trading arrangement necessitates PX to become a separate entity from the system operator (independent market operator). However, PX must have coordination with the ISO for ATC information and similarly ISO should have co-ordination with TSOs to have DA Schedules dispatched and imbalance settlement via balancing power market.

Whenever the power flow schedule in a particular transmission corridor is more than the transfer capacity of a corridor in power exchange, congestion is expected to occur. The power flow as scheduled cannot be transmitted, which may lead to a vulnerable situation. Therefore, prices are different under congestion [34], [35]. The higher cost generators within the area have to get active as lower-cost generators unable to fulfill demand [36], [37]. In such circumstances, TSOs in locally connected areas shall re-dispatch or countertrade to ensure the security of local networks [38].

$$Q_n(p) = \frac{p}{msi}\left[u\left(Q_n - Q_{n\,\min}\right) - u\left(Q_n - Q_{n\,\max}\right)\right] \quad (7)$$

$$Q_n(p) = p\sum_{i=1}^{N} \frac{1}{msi}\left[u\left(Q_n - Q_{n\,\min}\right) - u\left(Q_n - Q_{n\,\max}\right)\right] \quad (8)$$

C. BEST CASE PRACTICES FOR CROSS-BORDER POWER TRADE

In this subsection, some best-case practices of cross-border power trade are discussed that may be taken as an instance for grid interconnection among SMSs.

1) SOUTH AFRICAN POWER POOL (SAPP)

SAPP member states include Zimbabwe, Zambia, Tanzania, Swaziland, Namibia, Mozambique, Malawi, Lesotho, Congo, Botswana, and Angola. The primary purpose of the South African Power Pool (SAPP) is to ensure a reliable and economical supply of electricity among the member states. SAPP member states are aimed to fulfill their energy demand at an affordable cost with minimum environmental pollution [41]. SAPP system interconnections are shown in Fig. 8. It can be seen in the figure that if a member state under SAPP has surplus power available, it will be able to help energy deficit state to fulfill latter's power requirements through grid interconnection.

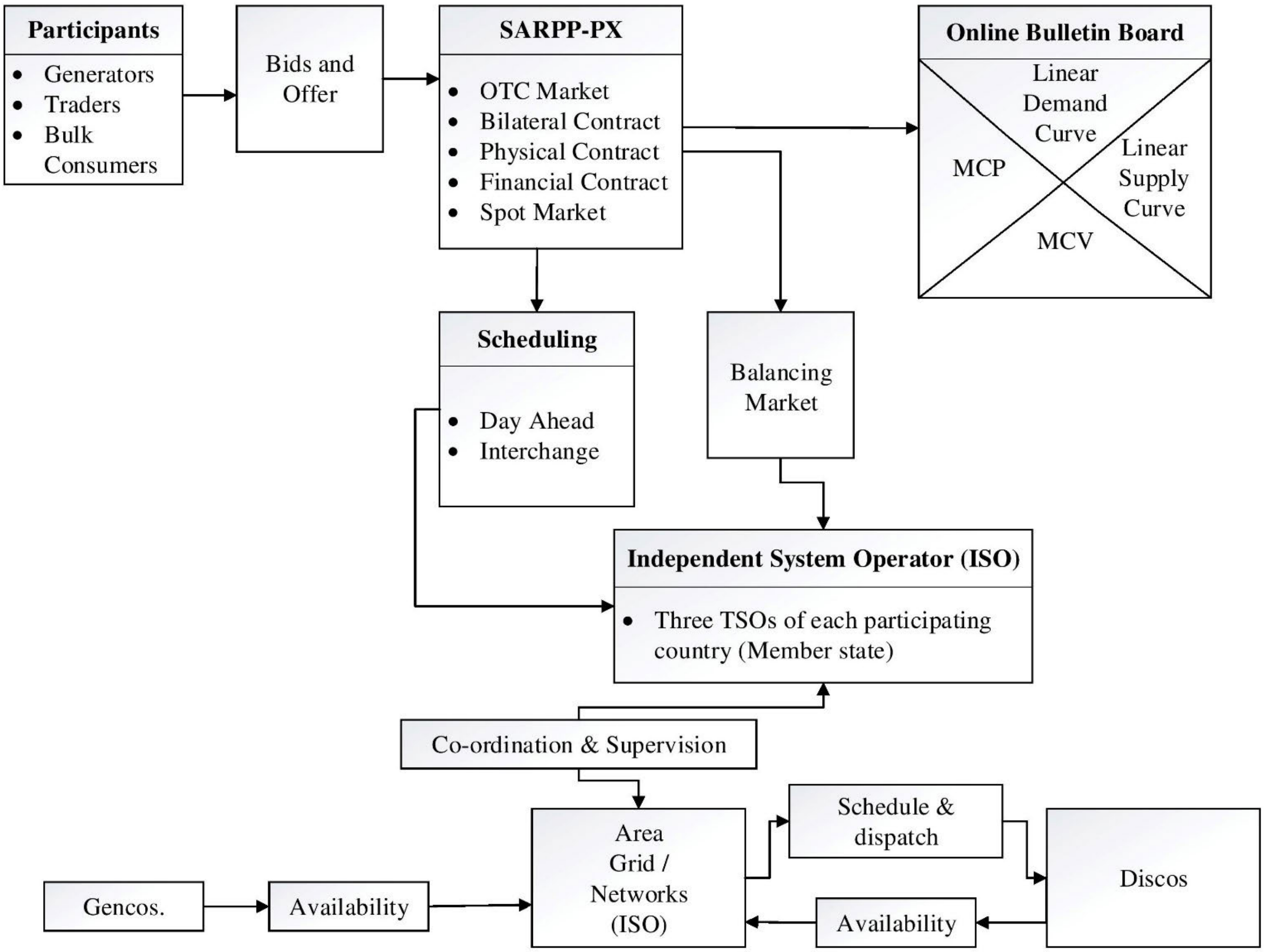


FIGURE 7. SAARC regional power pool model.

In Table 8, negotiated bilateral contracts between SAPP members have been specified. Main power sellers in a region are Eskom, RSA, Zambia, and ZESO. Their buyers are mostly neighboring countries but some countries who need to get power through transferring countries have a firm contract in place. It can be seen from a table that no. of buyers are greater than no. of sellers as most of the member states are dependent on imports to fulfill their power requirements. Among all member states, Eskom imports more power as it imports power from HCB, Mozambique and then feeds power to MOZAL (950MW), aluminum smelter and EDM (300MW) [42].

2) NORDIC POWER POOL

The cross-border power trade is made functional amongst five Scandinavian countries through the Nordic Power Pool. The member states under this power pool are Sweden, Norway, Denmark, Finland, and Iceland. It can be seen in Fig. 9 that power trade amongst all member states is balanced except power flows between Sweden and Finland. The net imports of Finland from Sweden were 14.3 TWh in 2012, which is the highest but a year later it dropped down to 12.2 TWh. The highest combined power flow was between Norway and Sweden which reached up to 14 TWh [43].

VIII. RELEVANT STUDY CASE

In this paper, different bidding scenarios for power exchange are studied and a uniform pricing approach is considered. For simplicity, two supply bidders are picked out from every area apart from power being retrieved from a local generator during congestion. Table 9 below contains the supply bid data for SMSs. We have divided bidding strategies into two different types and accordingly, two cases are being considered:

1- Case 1: Linear supply bid with fixed demand (single-sided bid market)
2- Case 2: Linear supply bid with linear demand bid (double-sided bid market)

A. CASE 1

Here a constant demand of 525 kW is considered with Table 9 representing linear bid data and Table 10 displaying output payments under different scenarios.

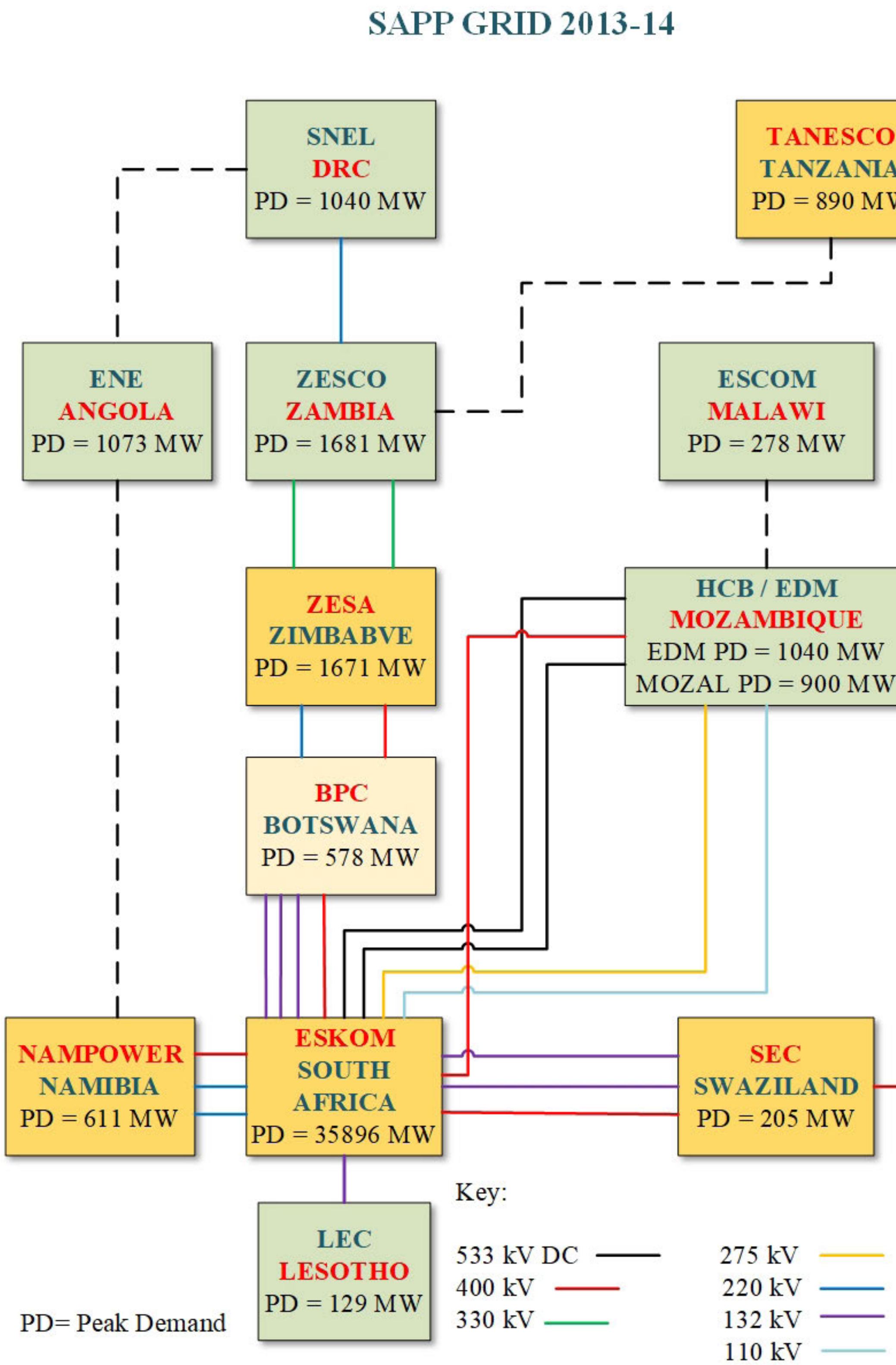


FIGURE 8. SAPP system [38].

As per the contents of Table 10, the value of MCP was calculated considering the unavailability of a local generator. It comes out to be 4.62 cents/kWh for the fixed demand of 525 kW while MCP calculated with the availability of local generation up to 45kW is 4.22 cents/kWh. The demand is met partially by local generator for cross border power exchange in case of local generator availability.

TABLE 8. Negotiated bilateral contracts among SAPP member states [41].

S.No.	From	To	Supply Capacity, MW	Start Date	Expiry Date	Utility Comments Updated, Keep or Delete Contract	Type (Firm or Non firm)
1	HCB	ESKOM	1150	1998	2030		Firm
2	ESKOM	SEC	250	1 Sep 2000	1 Sep 2025		Firm
3	ESKOM	LEC	24	1 Jun 2005	Indefinite		Firm
4	ESKOM	BPC	150	1 Jan 2008	31 Dec 2012		Firm
5	HCB	ESKOM	250	31 Mar 2008	14 Dec 2014		Firm
6	HCB	EDM	300	2 May 1984	31 Mar 2030		Firm wheeling
7	ESKOM	NamPower	350	1 Jul 2006	31 Mar 2017		Non-Firm
8	HCB	ZESA	100	1997	2014		Firm
9	HCB	ZESA	As available	2008	2014		Non-Firm
10	HCB	EDM	200	2008	2030		Firm
11	EDM	SEC	50	2003	Renewed annually		Firm
12	EDM North	EDM South	300	1992	Indefinite		Firm
13	EDM South	EDM North	300	1992	Indefinite		Firm
14	EDM	NamPower	50	2008	Renewed annually		Firm
15	EDM	BPC	50	2007	Renewed annually		Firm
16	EDM	ZESA	50	2011	Continuous/Renewable		Non-Firm
17	EDM	LEC	50	2008	Renewed annually		Firm
18	ZESCO	EDM	100	2009	Renewed annually	Keep	Firm
19	EDM	ZESCO	As required	2011	Continuous/Renewable	Keep	Non-Firm
20	ZESCO	ZESA	200	2009	Renewed annually	Keep	Non-Firm
21	ZESCO	ESKOM	300	2009	-	Keep/Not active	Non-Firm
22	EDM	ESKOM	As available	1 Apr 2010	31 Mar 2012		Firm
23	EDM	ESKOM	100	1 Oct 2009	Renewed every 2nd year		Firm wheeling
24	ZESA	NamPower	150	2008	2013		Firm
25	ZESCO	NamPower	50	Sep 2009	Sep 2019	Keep/Active	Firm
26	SNEL	BPC	50	2009	Continuous/Renewable		Firm
27	SNEL	ZESA	50	1992	2013		Firm
28	SNEL	ZESA	50	1992	2013		Non-Firm
29	ESKOM	ZESCO	300	2009	-	Keep/Not very active	Non-Firm
30	ESKOM	ZESA	As available	2009			Non-Firm
31	ZESA	ESKOM	As available	Jul 2010	Renewed annually		Non-Firm
32	ZESCO	BPC	100	Aug 2014	Renewed annually	Keep/Active	Non-Firm
33	ZESCO	SNEL (KCC)	40	Nov 2014	Renewed annually	Keep/Active	Firm
34	ZESCO	SNEL	100	1 Jul 2012	Renewed annually		Non-Firm

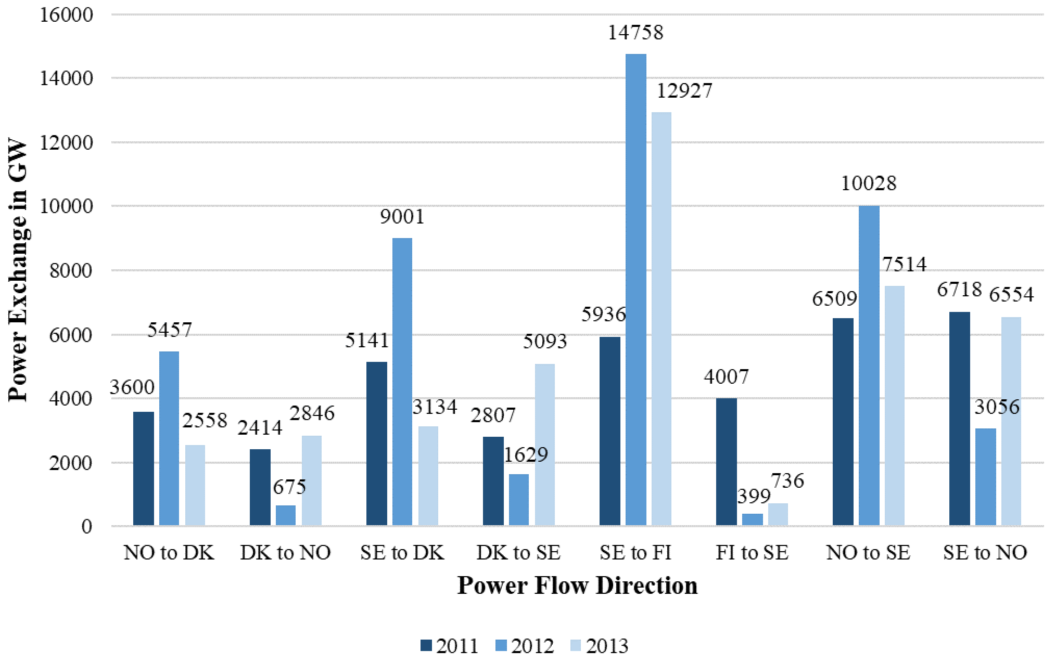


FIGURE 9. Nordic power exchange 2011-2013 [43].

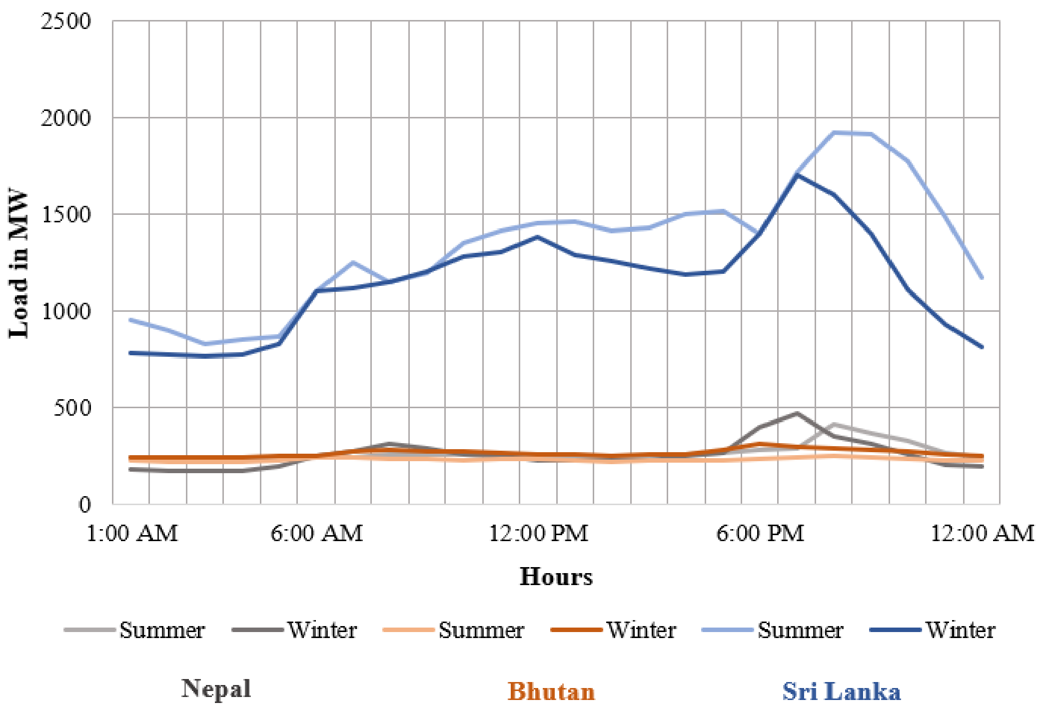


FIGURE 10. Load curve of Nepal, Bhutan, and Sri Lanka.

B. CASE 2

In the competitive electricity market, bids of demand-side participants are also catered. In this paper, we have considered 24 demand-side bidders for simplicity and their bid data are given in Table 11. The payments at multiple MCP and their corresponding output are also shown in Table 12. The aggregated supply and demand curves in Fig. 6. having their intersection point at 5.91 cents/kWh and 671.43 cents.

As per the values given in Table 12, the value of MCP calculated with the availability of local generation up to 45kW is 5.65 cents/kWh. The demand is met partially by local generator for cross border power exchange in case of its availability. The reduction in spot price which is being caused by the elasticity of demand bidders causes consumption among them to be increased.

TABLE 9. Linear bid data.

S.No.	Supply bidders	msi (cents/kWh^2)	Q_{gmax}	Q_{gmin}
1	Bidder 1 (Pakistan)	0.20	40	10
2	Bidder 2 (Pakistan)	0.19	55	10
3	Bidder 3 (Pakistan)	0.18	65	10
4	Bidder 4 (Sri Lanka)	0.16	50	10
5	Bidder 5 (Sri Lanka)	0.15	55	10
6	Bidder 6 (Sri Lanka)	0.14	60	10
7	Bidder 7 (Afghanistan)	0.12	50	10
8	Bidder 8 (Afghanistan)	0.11	60	10
9	Bidder 9 (Afghanistan)	0.10	70	10
10	Bidder 10 (Bangladesh)	0.40	40	10
11	Bidder 11 (Bangladesh)	0.39	40	10
12	Bidder 12 (Bangladesh)	0.38	40	10
13	Bidder 13 (Nepal)	0.36	40	10
14	Bidder 14 (Nepal)	0.35	40	10
15	Bidder 15 (Nepal)	0.34	40	10
16	Bidder 16 (Bhutan)	0.32	40	10
17	Bidder 17 (Bhutan)	0.31	40	10
18	Bidder 18 (Bhutan)	0.30	40	10
19	Bidder 19 (India)	0.28	40	10
20	Bidder 20 (India)	0.27	40	10
21	Bidder 21 (India)	0.26	40	10
22	Bidder 22 (Maldives)	0.24	40	10
23	Bidder 23 (Maldives)	0.23	40	10
24	Bidder 24 (Maldives)	0.22	40	10

C. ANALYSIS OF THE STUDY CASES

The results of both cases being mentioned above are analyzed having a total of 24 bidders. In the first case, the demand for these bidders was fixed at 525 kW and MCP calculated comes out to be 4.6223 cents/kWh. As per Table 10 contents, it displays the bidding quantity of each supplier who is participating in bidding and the amount calculated at MCP of 4.6223 cents/kWh is 2426.693 cents. However, when a local generator is active and supplying 45kW then MCP gets reduced to 4.2261 cents/kWh and the total amount of money at this MCP is 2155.295 cents.

In the second case, we have a total of 24 bidders. The supply bidders are responsible for meeting the variable requirements for demand bidders. Fig. 6 shows the aggregate demand and supply plots and with the help of the intersections of these plots, we can determine MCP and MCV. In Table 12, we can see MCV or total demand of bidders which is 671.43 kW, bidding quantity of supplying bidder and MCP which is 5.91 cents/kWh. The total amount of money calculated at MCP of 5.9 cents/kWh is 3696.156 cents. Upon consuming 45 kW power from a local generator, the MCP dropped down to 5.65 cents/kWh. At this

TABLE 10. Output and payment under different cases.

S.No.	Supply bidders	Output KW at 4.6223 cents	Payment at 4.6223 cents	Output KW at 4.2261 cents	Payment at 4.2261 cents
1	Bidder 1	23.1114	106.8271	21.1304	89.2987
2	Bidder 2	24.3894	112.7619	22.3043	94.5234
3	Bidder 3	25.6793	118.6967	23.4782	99.2208
4	Bidder 4	28.8892	133.5338	26.4130	111.6234
5	Bidder 5	30.9467	143.7012	28.2997	119.5965
6	Bidder 6	33.0162	152.6101	30.1863	127.5696
7	Bidder 7	38.5189	178.0451	35.2173	148.8312
8	Bidder 8	42.3648	195.8496	38.7391	163.7143
9	Bidder 9	46.2227	213.6541	42.2608	178.5974
10	Bidder 10	11.5557	53.4135	10.5652	44.6493
11	Bidder 11	11.8538	54.8192	10.8433	45.8243
12	Bidder 12	12.1639	56.2248	11.1213	46.9993
13	Bidder 13	12.8396	59.3484	11.7391	49.6104
14	Bidder 14	13.2113	61.0939	12.0844	51.0695
15	Bidder 15	13.5949	62.8394	12.4296	52.5286
16	Bidder 16	14.4446	66.7669	13.2065	55.8117
17	Bidder 17	14.9561	68.9925	13.6467	57.6721
18	Bidder 18	15.4076	71.2180	14.0869	59.5325
19	Bidder 19	16.5081	76.3050	15.0931	63.7848
20	Bidder 20	17.1431	79.2399	15.6736	66.2381
21	Bidder 21	17.7780	82.1747	16.2541	68.6913
22	Bidder 22	19.2595	89.0225	17.6087	74.4156
23	Bidder 23	20.1349	93.069	18.4091	77.7981
24	Bidder 24	21.0103	97.1155	19.2094	81.1806
	Local generator	0	0	45	126.783
	Total	525	2426.6928	525	2155.2945

MCP, the total amount calculated is 3640.14 cents. Moreover, the total quantity supplied by each bidder is reduced but overall demand/supply is increased to 686.84 kW as shown in Table 12.

As we have seen in the first case, the power demand is fixed but supply is variable which is most commonly practiced in the power markets. However, in real life, the demand can never be fixed and demand's fine-tuning is done through balancing the power market. The second case shows that power demand is changing daily. Latter case is relatively a new concept and it may be followed in the larger market with a good power quantity.

IX. LOAD SCENARIOS (LOAD FACTOR AND LOAD CURVE) IN SAARC STATES

Information about the load curve along with the load factors of different SMSs is found much useful to come up with a set of guidelines to suggest favorable scenarios of cross border power trading. The member states having lower load factors may export power to other SMSs for effective utilization of their installed capacity during low peak season. With the help of load curves and bar charts of the load factor, we will further elaborate that which states can trade power either as an exporter or an importer of electricity. The load curves and load factors for all SMSs are presented below:

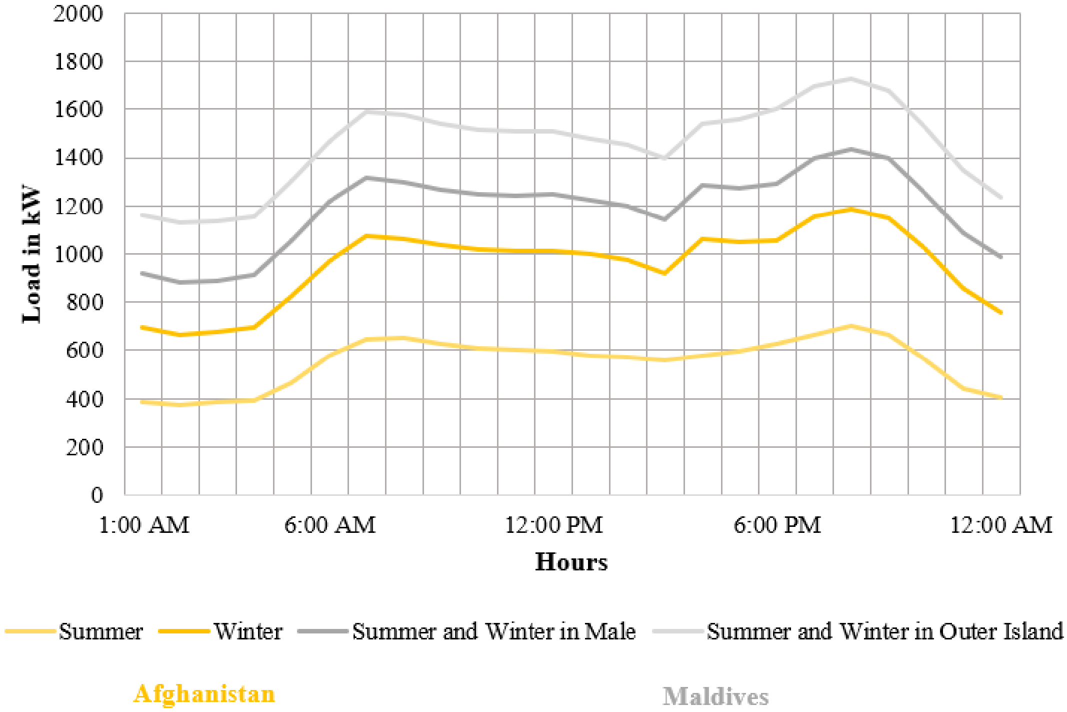


FIGURE 11. Load curve of Afghanistan and Maldives.

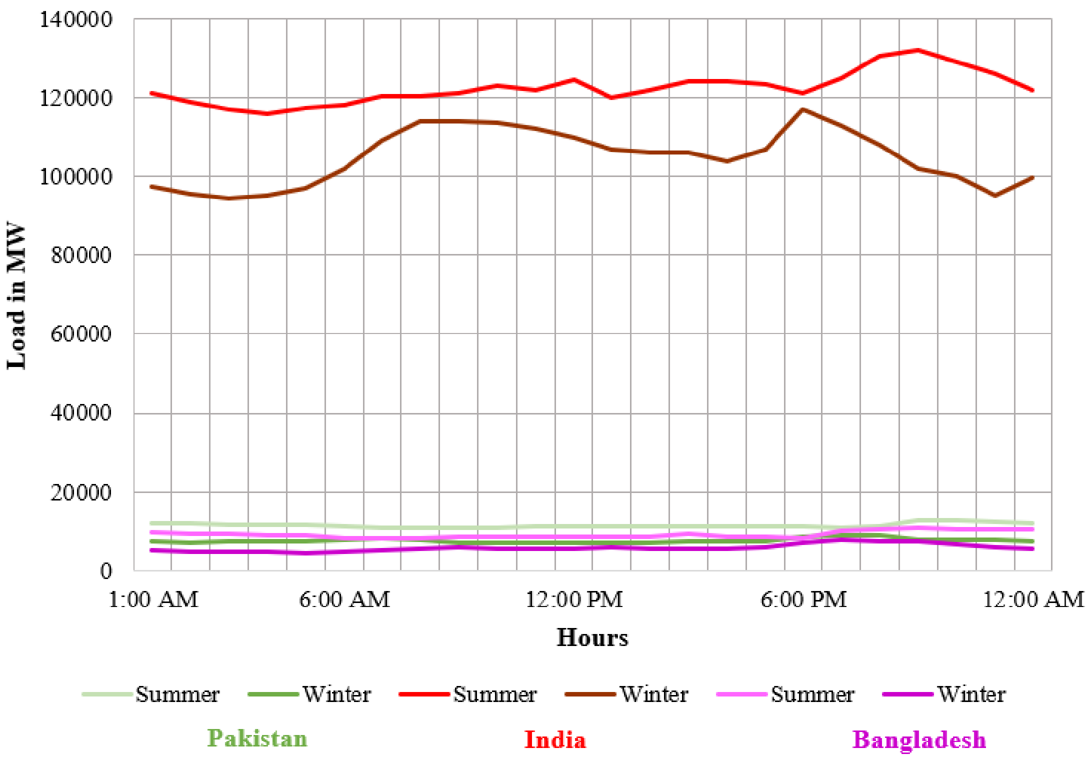


FIGURE 12. Load curve of Pakistan, India and Bangladesh.

A. NEPAL

The typical daily load curve of Nepal for summer and winter is shown in Fig. 10 having a peak load of 415MW in summer while 465MW in winter. The load factor of Nepal is one of the lowest amongst SMS with 64.1% in summer and 55.1% while in winter as depicted in Fig. 13 [7]. Nepal is significantly dependent on power imports from India which makes up 18% of its total power demand. They have mostly hydroelectric power plants that remain dormant during the winter season. Therefore, Nepal should increase its power

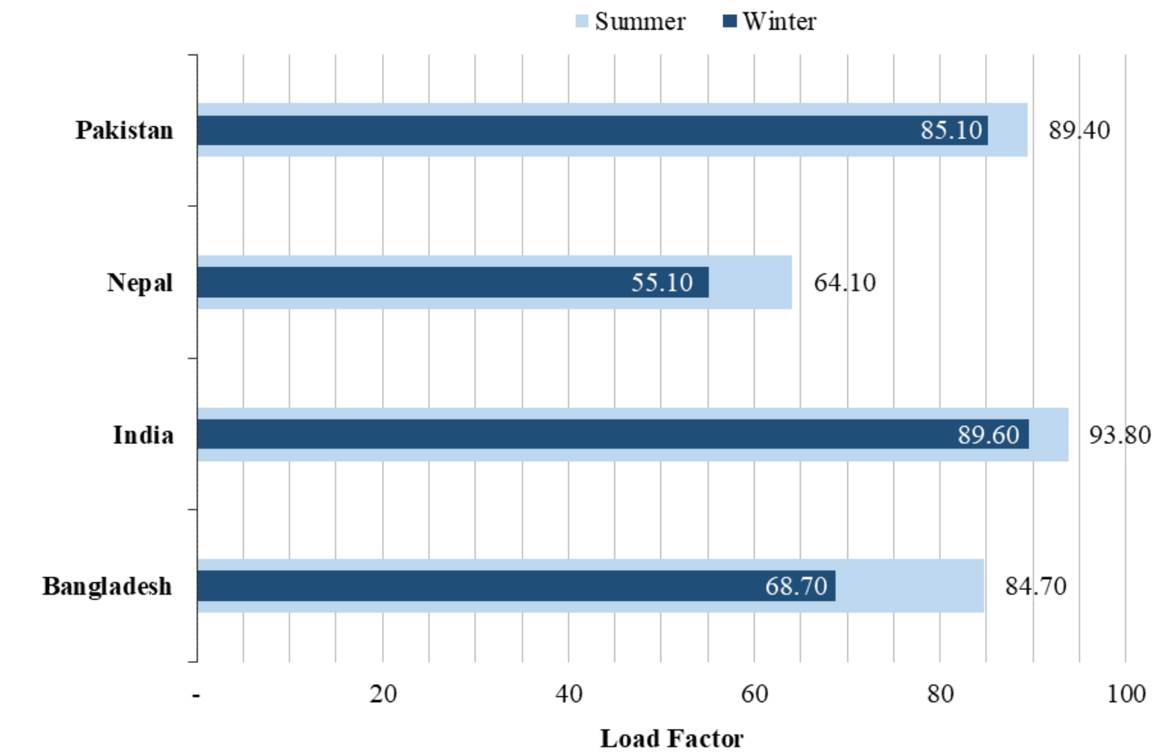


FIGURE 13. Load factor of Pakistan, Nepal, India, and Bangladesh in summer and winter.

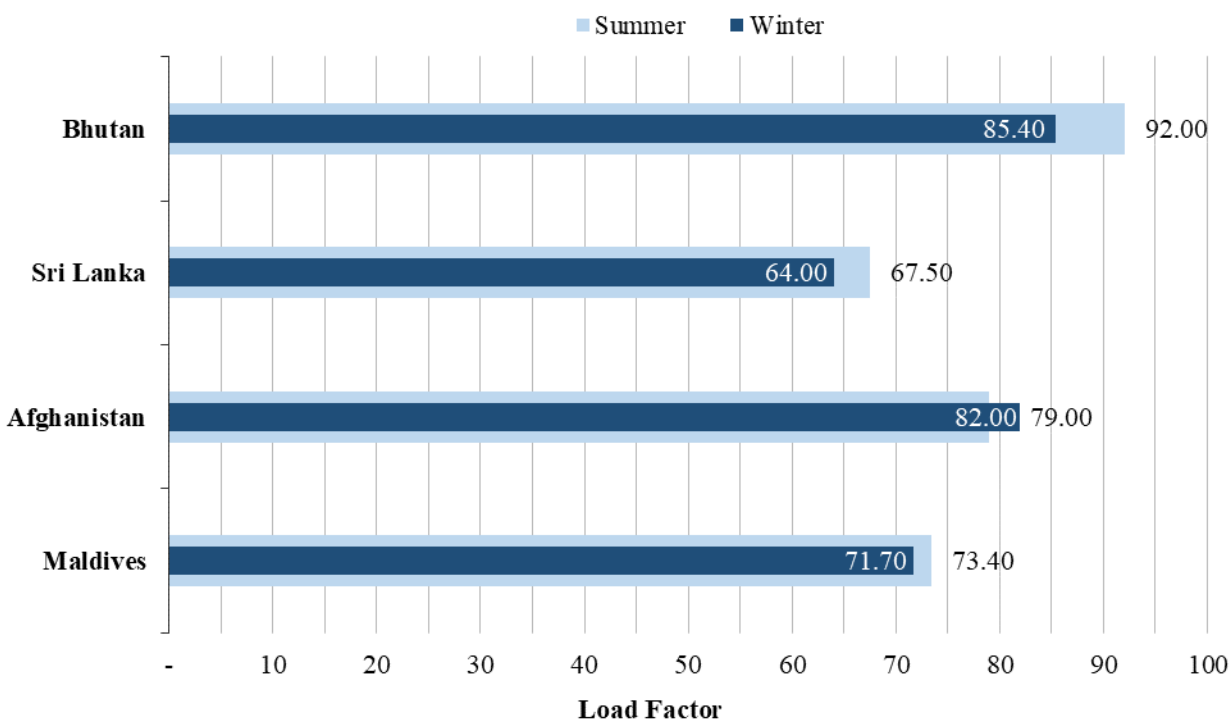


FIGURE 14. Load factor of Bhutan, Sri Lanka, Afghanistan and Maldives in summer and winter.

generation capacity considering diversification of sources in its energy mix for enhancing its load factor.

B. BHUTAN

The typical daily load curve of Bhutan for summer and winter is shown in Fig. 10 having a peak load of 250MW in summer while 310MW in winter. The load factor in India varies from 92% to 85.4% in summer and winter seasons respectively as depicted in Fig. 14 [8]. As mentioned before, Bhutan is supplying total electrical power of 1416 MW to India and yet it possesses a relatively lower load factor in winter due to heavy dependence on power production from hydroelectric

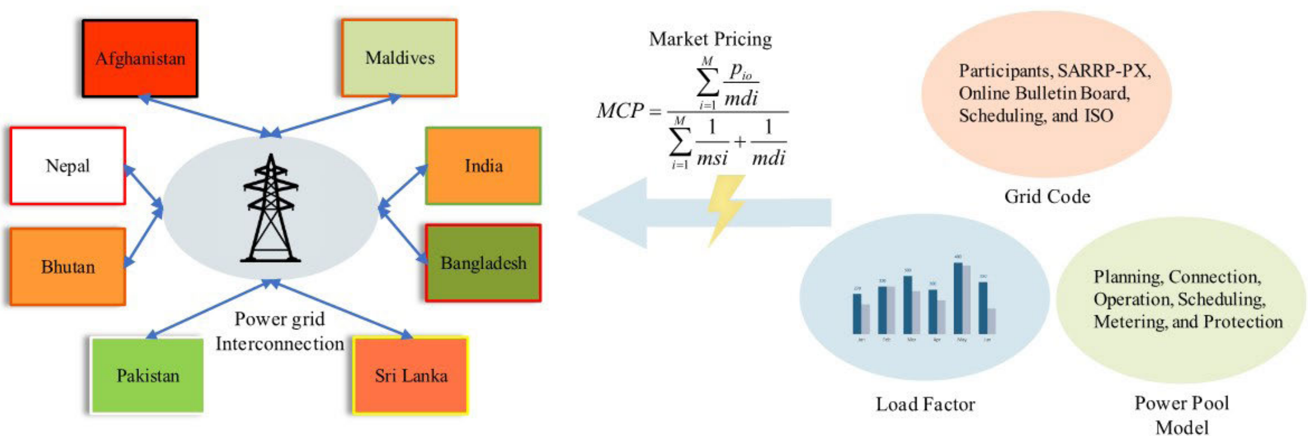


FIGURE 15. Grid code synchronization and power pool model for cross-border power trade in SAARC region.

TABLE 11. Linear demand bid data.

S.No.	Supply bidders	mdi (cents/kWh^2)	p_{io} (cents/kWh)
1	Bidder 1	0.34	15.5
2	Bidder 2	0.31	15.25
3	Bidder 3	0.27	15
4	Bidder 4	0.33	14
5	Bidder 5	0.33	12
6	Bidder 6	0.33	13
7	Bidder 7	0.32	12
8	Bidder 8	0.31	11.5
9	Bidder 9	0.31	11
10	Bidder 10	0.48	19
11	Bidder 11	0.46	18
12	Bidder 12	0.44	17.5
13	Bidder 13	0.45	21
14	Bidder 14	0.44	21
15	Bidder 15	0.42	20.5
16	Bidder 16	0.40	20
17	Bidder 17	0.40	20
18	Bidder 18	0.40	19.5
19	Bidder 19	0.40	18
20	Bidder 20	0.39	17.5
21	Bidder 21	0.38	17
22	Bidder 22	0.36	16.5
23	Bidder 23	0.35	16.5
24	Bidder 24	0.35	16

power plants (HEP). It can be recovered a bit more for both seasons because yet there is a potential of increasing installed capacity by 8500MW through hydroelectric based projects. Moreover, the concerned authorities in Bhutan shall consider diversifying their energy mix as HEP alone will not cater to local power demands and export demands.

C. SRILANKA

The typical daily load curve of Sri Lanka for summer and winter is shown in Fig. 10 having a peak load of 1920MW in summer while 1700MW in winter. The load factor for the country is amongst the least in comparison with other SMSs being at 67.5% in summer and 64% in winter as depicted in Fig. 14 [10]. Since 2018, the country is facing power outages due to a lack of installed generation capacity. It eventually led Sri Lanka to fulfill its power demand through electricity imports. Sri Lankan government envisions to be a self-sufficient nation by 2030 by increasing their installed capacity from 4043MW to 6900MW. Increasing the installed capacity will eventually increase the load factor and enable the state to reap financial benefits of exporting electricity to other SMSs.

D. AFGHANISTAN

A typical daily load curve of Afghanistan for summer and winter is shown in Fig. 11 having a peak load of 700MW in summer while 490MW in winter. Load factor in Afghanistan is 79% and 82% in summer and winter respectively, which is quite moderate as compared with other member states as depicted in Fig. 14 [6]. It has been noticed that the gap between power supply and demand is being increased in Afghanistan over the last 5 years. The hydroelectric power plants yield peak output during summer but lag considerably in winter. These plants have a minimal reservoir and thus unable to provide storage for more than a few hours. To prevent the increasing demand and supply gap, it has to capitalize on untapped hydroelectric power production of 23000MW for increasing their generation capacity. It will put Afghanistan in a position to not only cater to their local power demand but also fulfilling SMSs power requirements.

E. MALDIVES

A typical daily load curve of Maldives is shown in Fig. 11 for the island of Male. The load curve remains the same throughout the year for both seasons. The load curve in Fig. 11 displays the peak value of 17500kW for Male island. The load factor for Male island stands at a decent figure of 71.7% in

TABLE 12. Payment at various MCP and corresponding output.

S.No.	Supply bidders	Output KW at 5.9115 cents	Payment at 5.9115 cents	Output KW at 5.6598 cents	Payment at 5.6598 cents
1	Bidder 1	29.5574	174.7286	28.2988	153.1655
2	Bidder 2	31.1995	184.4359	29.8701	162.0636
3	Bidder 3	32.8416	194.1431	31.4431	170.9617
4	Bidder 4	36.9468	218.411	35.3735	193.2069
5	Bidder 5	39.5859	234.0118	36.9002	207.5076
6	Bidder 6	42.2249	249.6125	40.4269	221.8082
7	Bidder 7	49.2624	291.2147	47.1647	259.9428
8	Bidder 8	54.1887	320.3362	51.8791	286.6361
9	Bidder 9	59.1149	349.4577	56.5976	313.3311
10	Bidder 10	14.7787	87.36429	14.1494	73.08277
11	Bidder 11	15.1676	89.66327	14.5218	75.1902
12	Bidder 12	15.5565	91.96225	14.8941	77.29763
13	Bidder 13	16.4208	97.07156	15.7216	81.98111
14	Bidder 14	16.9038	99.9265	16.184	84.5982
15	Bidder 15	17.3867	102.7815	16.6464	87.21529
16	Bidder 16	18.4734	109.2055	17.6876	93.1083
17	Bidder 17	19.0892	112.8458	18.2768	96.4428
18	Bidder 18	19.705	116.4861	18.8659	99.7772
19	Bidder 19	21.1125	124.8065	20.2134	107.4038
20	Bidder 20	21.9245	129.6067	20.9909	111.804
21	Bidder 21	22.7365	134.4068	21.7683	116.2042
22	Bidder 22	24.6312	145.6073	23.5823	126.4711
23	Bidder 23	25.7508	152.2259	24.6543	132.5381
24	Bidder 24	26.8704	158.8444	25.7262	138.6051
	Local generator	0	0	45	169.794
	Total	671.4296	3696.156	686.837	3640.137
	Demand side bidding				
1	Bidder 1	28.2015	166.7132	28.9419	155.2221
2	Bidder 2	30.9314	182.8507	31.2677	170.2156
3	Bidder 3	33.6612	198.9882	34.5935	186.209
4	Bidder 4	24.5106	144.8944	25.2735	133.4597
5	Bidder 5	33.6612	135.9376	23.2584	124.8843
6	Bidder 6	21.4803	126.9808	22.2432	116.3088
7	Bidder 7	19.0266	112.4757	19.8133	102.556

TABLE 12. *(Continued.)* **Payment at various MCP and corresponding output.**

8	Bidder 8	17.7206	104.7553	18.5191	95.2359
9	Bidder 9	16.4146	97.03491	17.2266	87.91581
10	Bidder 10	27.2677	161.193	27.7922	147.715
11	Bidder 11	26.2301	155.0581	26.7651	141.9058
12	Bidder 12	25.1924	148.9249	25.7397	136.0983
13	Bidder 13	34.2921	202.7177	34.8642	186.73009
14	Bidder 14	33.3555	197.181	33.9213	182.4042
15	Bidder 15	32.4189	191.6443	32.9783	177.0673
16	Bidder 16	33.5441	198.2959	34.1434	183.6655
17	Bidder 17	33.7577	199.5586	34.372	162.1718
18	Bidder 18	33.9713	200.8213	34.6006	186.2492
19	Bidder 19	30.2213	178.6532	30.8506	165.0249
20	Bidder 20	29.7008	175.5763	30.3467	162.1718
21	Bidder 21	29.1803	172.4993	29.8427	159.3204
22	Bidder 22	29.4125	173.872	30.1118	160.7435
23	Bidder 23	29.1184	172.1334	29.8277	159.2353
24	Bidder 24	28.8243	170.3948	29.5435	157.627
	Total	671.4296	3696.156	686.837	3640.137

summer while in winter it slightly jumps to a value of 73.4% as shown in Fig. 14. The load factor values for the island almost remains the same throughout the year [24]. The Maldives already has a status of a self-sufficient member state in the SAARC region as it is already fulfilling its power demand on his own. Currently, Maldives is reliant upon thermal power plants having its fuel imported from other countries. The Maldives, unlike any other SMSs, does not have many resources to increase their installed capacity for load factor improvement except for biomass. The country has significant biomass production that can also be utilized to increase its installed capacity.

F. PAKISTAN

A typical daily load curve of Pakistan for summer and winter is shown in Fig. 12 having a peak load of 12,900MW in summer while 9000MW in winter. The load factor for a country is better in summer with 89.4% in comparison with other member states while in winter, it drops to a reasonable value of 85.1% as depicted in Fig. 13 [6]. There is a huge potential in power generation from HEP in Pakistan as only 34% of 45000MW is being used. Similarly, potential of wind and solar energy is still untapped in Pakistan, which is an energy deficit country with a shortfall of 5000MW. It is believed that Pakistan can certainly overcome energy deficiency by focusing on renewable sources development and improving its load factor in low peak season i.e. winter.

G. INDIA

A typical load curve of India for summer and winter is shown having a peak load of 132GW in summer while 117GW in winter in Fig.12. The load factor of India is shown in Fig. 13 [8]. India is almost a couple of years away from becoming a self-sufficient member state. The only problem lies in the energy mix of India as it is heavily dependent on coal-fired power plants. It led the government to invest heavily in renewables like solar, wind, etc. to increase their installed capacity for fulfilling local demand and increase exports as well. Moreover, their power trade with Sri Lanka is already in infant stages so they can also trade more power with them to further increase their load factor.

H. BANGLADESH

A typical load curve of Bangladesh for summer and winter is shown in Fig. 12 having a peak load of 10,860MW in summer while 7700MW in winter. The load factor in Bangladesh is quite reasonable in summer with 84.7% while in winter, it is very low with a value of 68.7% as shown in Fig. 13.

The member states with almost compatible load factors in both seasons i.e. summer and winter are Sri Lanka and

Maldives. Maldives exhibits similar behavior with 71.7% load factor for Male Island in winter and 73.4% in summer. Remaining SMSs have managed to achieve a load factor of 80% or more in both summer and winter which leads us to a conclusion that they need to further increase their installed capacity for increasing their generation and alternatively they can improve load factor by increasing power trade with the neighboring SMSs [25]. A pictorial representation of proposed model through technical standardization, in-depth analysis of load factor of different SAARC member states, market pricing, etc. for grid interconnection in the SAARC region is shown in Fig. 15.

X. CONCLUSION

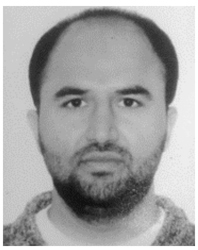
This study assessed the current power trade scenario in SAARC region and identified the barriers that are restricting its implementation. Importantly, a power trading model is proposed which helps SMSs overcome power shortages. The discrepancies in the grid code of SMSs need immediate attention as they are limiting power trade in SAARC region. Therefore, these gaps are highlighted and eventually standardization of technical data is proposed to unify all member states grid code to ensure seamless cross-border power trade. Afghanistan still has to draft its grid code so it can do a transition of grid code onto a standardized format with relative ease.

The cooperation between all member states is of great importance as the majority of member states need harmonization of grid codes through some amendments within their existing grid codes. In addition, it is concluded that in order to promote cross border power trade, tariffs of SMSs need to be unified, and for that, the proposed power pool model may help achieve the said objectives of power trade. The presented study cases are considered key findings for setting up a transparent bidding process and power trading market. The presented load scenarios in the SAARC states give vital guidelines for all SAARC states to encourage cross-border power flow. It has been asserted that at regional level cross border power trade can certainly help member states to overcome power deficiency. However, an area that still needs to be tapped is what if power trade is translated from intra-regional to inter-regional level e.g. SAARC region can opt for cross border power trade with other regions like ASEAN etc. Therefore, future work should be focused towards this area as it will benefit all member states considering all of them are connected through tie lines.

REFERENCES

[1] A. Singh, T. Jamasb, R. Nepal, and M. Toman, "Electricity cooperation in South Asia: Barriers to cross-border trade," *Energy Policy*, vol. 120, pp. 741–748, Sep. 2018.
[2] A. D. Ellerman and B. K. Buchner, "The European Union emissions trading scheme: Origins, allocation, and early results," *Rev. Environ. Econ. Policy*, vol. 1, no. 1, pp. 66–87, 2007.
[3] R. F. Pastor, *Building Regional Power Pools: A Toolkit*. Washington, DC, USA: World Bank, 2008.
[4] P. V. Srinivasan, "Regional cooperation and integration through cross-border infrastructure development in South Asia: Impact on poverty," Asian Develop. Bank, Mandaluyong, Philippines, Tech. Rep. 14, 2012.
[5] Ministry of Energy Government of Nepal, "Agreement between the Government of Nepal and the Government of Republic of India on electric power trade, cross border transmission inter connection and grid connectivity," Ministry Energy, Government Nepal, Kathmandu, Nepal, Tech. Rep., 2014.
[6] J. Yang, F. Li, and L. Freeman, "A market simulation program for the standard market design and generation/transmission planning," in *Proc. IEEE Power Eng. Soc. Gen. Meeting*, vol. 1, Jul. 2003, pp. 442–446.
[7] Z. Ngadiron, N. H. Radzi, and M. Y. Hassan, "The generation revenue and demand side assessment in pool-based market model for competitive electricity markets," in *Proc. IEEE Int. Conf. Power Energy (PECon)*, Nov. 2016, pp. 372–377.
[8] T. Greve, "Market design in the smart grid," in *Smart Grid Handbook*. Hoboken, NJ, USA: Wiley, 2016, pp. 1–9.
[9] J. A. Rosas-Flores, "Elements for the development of public policies in the residential sector of Mexico based in the Energy Reform and the Energy Transition law," *Energy Policy*, vol. 104, pp. 253–264, May 2017.
[10] D. Kirschen and G. Strbac, *Fundamentals of Power System Economics*. Hoboken, NJ, USA: Wiley, 2018.
[11] *Power Services Regulation Act*, Ministry Energy Water, Kabul, Afghanistan, 2015.
[12] R. M. Holmukhe and M. P. Kulkarni, "Infrastructural analysis of load dispatch centre," *Int. J. Comput. Appl.* vol. 1, no. 7, pp. 975–8887, 2010.
[13] Bhakar, Rohit, Narayan Prasad Padhy, and Hari Om Gupta, "State of art of the regulatory process in India," in *Proc. IEEE Power Energy Soc. Gen. Meeting-Conversion Del. Electr. Energy 21st Century*, Jul. 2008, pp. 1–8.
[14] *SAARC Energy Outlook 2030*, SAARC Energy Centre, Islamabad, Pakistan, 2018.
[15] *Harmonizing Transmission Grid Codes of SAARC Member States to Combat Regulatory Challenges for Intra Region Power Trading/Interconnections*, SAARC Energy Centre, Islamabad, Pakistan, 2015.
[16] G. L. Doorman and R. Van Der Veen, "An analysis of design options for markets for cross-border balancing of electricity," *Utilities Policy*, vol. 27, pp. 39–48, Dec. 2013.
[17] *Draft Regulations on Cross Border Trade of Electricity*, Central Electr. Regulatory Commission, New Delhi, India, 2017.
[18] S. Mukhopadhyay and S. K. Dube, "Status of power exchange in India: Trading, scheduling, and real time operation of regional grids," in *Proc. IEEE Power Eng. Soc. Gen. Meeting*, Jun. 2005, pp. 2866–2871.
[19] *Central Electricity Regulatory Commission New Delhi*, ERSS, XXI, Chief Engineer PTP, Chief Engineer C&R, and Dhurwa Engineer, New Delhi, India, 2017.
[20] M. A. H. Mondal, L. M. Kamp, and N. I. Pachova, "Drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh—An innovation system analysis," *Energy Policy*, vol. 38, no. 8, pp. 4626–4634, 2010.
[21] *Grid Code Regulation*, Bhutan Electr. Authority, Thimphu, Bhutan, 2008.
[22] M. J. Harper, "Implementing gridshare technology in rural Bhutan: Analyzing effects on electrical brownouts and assessing community acceptance," Ph.D. dissertation, Humboldt State Univ., Arcata, CA, USA, 2013.
[23] M. O. Oseni and M. G. Pollitt, *Institutional Arrangements for the Promotion of Regional Integration of Electricity Markets: International Experience*. Washington, DC, USA: World Bank, 2014.
[24] K. T. M. U. Hemapala and L. Neelawala, "Benchmarking of electricity distribution licensees operating in Sri Lanka," *J. Energy*, vol. 2016, Jan. 2016, Art. no. 2486319.
[25] A. Singh, T. Jamasb, R. Nepal, and M. Toman, *Cross-Border Electricity Cooperation in South Asia*. Washington, DC, USA: World Bank, 2015.
[26] P. Wijayatunga, D. Chattopadhyay, and P. N. Fernando, "Cross-border power trading in South Asia: A techno economic rationale," Asian Develop. Bank, Mandaluyong, Philippines, Tech. Rep. 38, 2015.
[27] J. H. Williams and R. Ghanadan, "Electricity reform in developing and transition countries: A reappraisal," *Energy*, vol. 31, nos. 6–7, pp. 815–844, 2006.
[28] T. Kalinowski and H. Cho, "Korea's search for a global role between hard economic interests and soft power," *Eur. J. Develop. Res.*, vol. 24, no. 2, pp. 242–260, 2012.
[29] A. Al-Sunaidy and R. Green, "Electricity deregulation in OECD (Organization for Economic Cooperation and Development) countries," *Energy*, vol. 31, nos. 6–7, pp. 769–787, 2006.
[30] R. Lisa, "The power of power: Regime dynamics and the Southern African power pool," Ph.D. dissertation, Stellenbosch Univ., Stellenbosch, South Africa, 2013.

[31] S. Mandelli, J. Barbieri, L. Mattarolo, and E. Colombo, ''Sustainable energy in Africa: A comprehensive data and policies review,'' *Renew. Sustain. Energy Rev.*, vol. 37, pp. 656–686, Sep. 2014.
[32] A. Etxegarai, P. Eguia, E. Torres, A. Iturregi, and V. Valverde, ''Review of grid connection requirements for generation assets in weak power grids,'' *Renew. Sustain. Energy Rev.*, vol. 41, pp. 1501–1514, Jan. 2015.
[33] A. Singh, P. Wijayatunga, and P. N. Fernando, ''Improving regulatory environment for a regional power market in South Asia,'' Asian Develop. Bank, Mandaluyong, Philippines, Tech. Rep. 45, 2016.
[34] M. Prabavathi and R. Gnanadass, ''Energy bidding strategies for restructured electricity market,'' *Int. J. Elect. Power Energy Syst.*, vol. 64, pp. 956–966, Jan. 2015.
[35] R. Meyer and O. Gore, ''Cross-border effects of capacity mechanisms: Do uncoordinated market design changes contradict the goals of the European market integration?'' *Energy Econ.*, vol. 51, pp. 9–20, Sep. 2015.
[36] Mishra, Akanksha, ''Congestion management of deregulated power systems by optimal setting of interline power flow controller using gravitational search algorithm,'' *J. Elect. Syst. Inf. Technol.*, vol. 4, no. 1, pp. 198–212, 2017.
[37] P. C. Bhagwat, J. C. Richstein, E. J. L. Chappin, K. K. Iychettira, and L. J. De Vries, ''Cross-border effects of capacity mechanisms in interconnected power systems,'' *Utilities Policy*, vol. 46, pp. 33–47, Jun. 2017.
[38] A. Hussain, M. Rahman, and J. A. Memon, ''Forecasting electricity consumption in Pakistan: The way forward,'' *Energy Policy*, vol. 90, pp. 73–80, Mar. 2016.
[39] R. Spalding-Fecher, B. Joyce, and H. Winkler, ''Climate change and hydropower in the Southern African Power Pool and Zambezi River Basin: System-wide impacts and policy implications,'' *Energy Policy*, vol. 103, pp. 84–97, Apr. 2017.
[40] Q. Wang, C. Zhang, Y. Ding, G. Xydis, J. Wang, and J. Østergaard, ''Review of real-time electricity markets for integrating distributed energy resources and demand response,'' *Appl. Energy*, vol. 138, pp. 695–706, Jan. 2015.
[41] S. Saroha and R. Verma, ''Cross-border power trading model for South Asian regional power pool,'' *Int. J. Electr. Power Energy Syst.*, vol. 44, no. 1, pp. 146–152, 2013.
[42] N. Lu, J. H. Chow, and A. A. Desrochers, ''Pumped-storage hydro-turbine bidding strategies in a competitive electricity market,'' *IEEE Trans. Power Syst.*, vol. 19, no. 2, pp. 834–841, May 2004, doi: 10.1109/TPWRS.2004.825911.



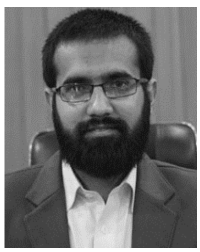
AZHAR UL-HAQ received the Ph.D. degree in electrical engineering, under the joint Research Doctoral Program, from the University of L'Aquila, Italy, and the University of Waterloo, Canada. He held a postdoctoral position with UNB, Canada. He has been working as a Research Assistant with the ECE Department, University of Waterloo, Canada. He has been working as an Assistant Professor of electrical engineering with the National University of Sciences and Technology, Islamabad, since November 2016. His research interests include grid integration of solar energy and control of electric vehicles' (EVs') smart charging; and direct load control strategies.

MOHAMMAD SHAHMEER HASSAN received the B.S. degree in electronic engineering from the Ghulam Ishaq Khan Institute of Engineering Sciences and Technology, Pakistan, in 2016. He is currently pursuing the M.S. degree in control systems from the College of Electrical and Mechanical Engineering, National University of Science and Technology, Islamabad, Pakistan. He worked as an Executive Electrical Engineer with Glee International, Pakistan. He have accomplished multiple government projects. His research interests include electric vehicles' (EVs') charging infrastructure, smart grid, and cross-border power trading.

MARIUM JALAL received the Ph.D. degree in electrical & telecommunications engineering from L'Aquila, Italy, in 2015. She was awarded with Gold Medal for the Best M.Sc. Thesis. From 2011 to 2014, she was a Marie-Curie Early Stage Researcher with the Center of Excellence for Research DEWS, University of L'Aquila, and with Wireless Embedded Systems Technologies Aquila s.r.l., Italy. She was a recipient of several research and travel grant awards.

SHOAIB AHMAD received the two M.S. level degrees and the Ph.D. degree in renewable-energies. He has vast experience in management of engineering and renewable energy projects. His professional strengths are in policy making, organizational development, engineering design, and systems engineering. He has also taught in universities and has three internationally published research articles to his credit. He is serving as the Deputy Director (Coord) with the SAARC Energy Centre, Islamabad, Pakistan. He is currently an Aeronautical Engineer. He is a member of many professional bodies.

MUHAMMAD ALMAS ANJUM received the Ph.D. degree in security and energy systems from NUST, Islamabad. He has been working as an HOD Research with the College of E&ME, National University of Sciences and Technology, Islamabad. He had published a total of 34 journal and conference papers. Moreover, he has also 3 patents and a book on his credit. His research interests include grid integration of solar energy and control of electric vehicles' (EVs') smart charging, and direct load control strategies.



IHSAN ULLAH KHALIL received the B.S. degree in electronic engineering from the International Islamic University Islamabad, Pakistan, in 2011. He is currently pursuing the Ph.D. degree in power systems from the College of Electrical and Mechanical Engineering, National University of Science and Technology, Islamabad, Pakistan. He is also a Lecturer with the Department of Electrical Engineering, Abasyn University, Peshawar. He has completed multiple commercial projects. His research interests include renewable energy harvesting, high power switched-capacitor converters, PV Faults, fault detection, Power system protection and reliability analysis of power converters.

ASAD WAQAR received the Ph.D. degree in electrical engineering. He worked as a Research Associate with RWTH Aachen, Germany. He has been working as an Associate Professor of electrical engineering with Bahria University, Islamabad Campus, Islamabad, since November 2016. His research interests include renewable energy, microgrid planning and control, power electronics applications in power systems, and power system operation and control. He also holds professional membership of Pakistan Engineering Council.