SAARC Study

Assess the Power Planning Criteria of SAARC Member States in the Perspective of Best Practices and Upcoming Regional Power Interconnections & Recommend Enhancements

December 2017

SAARC Energy Centre, Islamabad

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Foreword

Transmission regulatory regime formalizes and documents the practices, rules, standards and procedures for the guide users on three different aspects which include a. How will they connect to and use the grid?; b. What will be their roles and responsibilities?; and c. How will their conduct be regulated?. Grid Code is the major regulatory instrument comprising technical, legal and regulatory provisions. For meeting the challenges of rapid development of transmission grids, two factors are critically important with respect to the Grid Code. Firstly, the Grid Code should be considered as a dynamic document i.e. it needs to be regularly reviewed, updated and kept current in view of the emerging issues and opportunities viz-a-viz best international practices. Secondly compliance with the provisions of the Grid Code should be assigned higher priority and be never compromised.

As per SEC Study 'Harmonizing Transmission Grid Codes of SAARC Member States to Combat Regulatory Challenges for Intra-region Power Trading / Interconnections' undertaken in the FY 2015, Indian Grid Code is more stringent in almost all dimensions and also provides wider details as far as planning criteria is concerned. Indian transmission planning criteria specifies security and reliability limits to be considered at planning stage which are more stringent than the operational security and reliability limits. A planning margin is specified for voltage limits, thermal loading limits of lines and transformers, reactive capabilities of generators, fault levels etc. Grid Codes of other SAARC Member States do not specify conditions on planning margin and only specify operational security limits as planning criteria. It is high time that other Member States capitalize on the Indian success stories in the maximum possible extent.

SAARC Energy Centre (SEC) undertook the short term, in-house Study through its Action Program FY 2017 to assess the prevailing planning criteria of all the Member States, where applicable, to assess its currency in comparison to the best utility practices and suggest potential changes with respect to parameters including, but not limited to, renewable energy intermittency, fuel diversity, ever increasing load quantum and regional interconnectivity leading to SAARC Energy Ring. The Study is an in-house effort by Mr. Salis Usman, Program Leader (Energy Trade) and was peer-reviewed by Ms. Samreen Fatima Shirazi, Senior Team Lead, Power Planners International (Pvt.) Limited. Overall purpose of the Study is to sensitize the SAARC Member States on the best regional as well as international practices with respect to planning criteria which is an important regulation included in the Grid Code.

SEC looks forward to the comments and suggestions from the professionals to add further value to the Study report besides seeking proposals for future interventions to be undertaken by the SEC especially in the context of SAARC Energy Ring.

Muhammad Naeem Malik

Director, SEC

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I am highly grateful to the power planning professionals from all over the SARC Region, all the professional at SAARC Energy Centre for their sharing invaluable ideas and comments to materialize this intervention.

I am also thankful to two young engineers Engr. Hafza Rehman and Engr. Ahmad Usman Khan for supporting me enthusiastically and tirelessly while collecting and analyzing data to shape it into a meaningful research effort.

Finally, I am indebted to Engr. Ms. Samreen Fatima Shirazi for her concerned, thoughtful comments on the draft report that certainly added value to the study outcome.

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1. Introduction

For combating the gap in power demand and supply, huge investments in the power sector are anticipated during the next decade or so. However, the prevailing planning criteria of power transmission utilities which include planning basis certainly possess gaps in terms of renewable energy intermittency, fuel diversity, accelerating load quantum, regional interconnectivity, etc. that should be taken care of as ongoing processes.

SEC envisions undertaking an in-house study to assess the prevailing planning criteria of all the Member States, where applicable, to assess its currency in comparison to the best utility practices and suggest potential changes with respect to parameters including, but not limited to, renewable energy intermittency, fuel diversity, ever increasing load quantum and regional interconnectivity leading to SAARC Energy Ring.

Typically, there are three fundamental parameters in the Planning Criteria:

a. System reliability

   Is the system adequate and secure?

b. Steady state performance

   Is the normal operating state of the system within prescribed limits?

c. Stability

   Does the system remain “normal” or return to normal following a “disturbance”?

1.1 Purpose of Transmission System Planning

The purpose of transmission system planning is to develop a reliable and efficient transmission system for transferring power from areas of generation to areas of demand (load) under varying system conditions, while operating equipment within accepted ratings. The system conditions include - changing demand patterns, generation changes and equipment outages (planned or unplanned) (Transpower, n.d.).

1.2 Study Objectives

Following are the envisioned objectives for this in-house study:

a. Study the prevailing power planning criteria of the power transmission utilities of South Asia and of other parts of the world, where applicable

b. Assess the currency of the prevailing planning criteria in view of the best practices

c. Suggest potential changes with respect to parameters including, but not limited to, renewable energy intermittency, fuel diversity, ever increasing load quantum and regional interconnectivity leading to SAARC Energy Ring.

1.3 Rationale

Expansion and maintenance of power grid network remain vital activities for transmission of power from generation facilities to the distribution entities. Development and maintenance of grid is governed by the legal and technical document called Grid Code. Planning criteria, an important element of Planning Code is provided in the Grid Code with the objective to regulate grid planning exercise. It includes the policy, standards and guidelines for the planning and design of the transmission system.

1.4 Scope

For this Study, Planning Criteria of all the Member States, where available, has been considered and assessed for this purpose. Similarly, recommendations moving ahead in terms of promoting regional interconnection have been made for consideration by the stakeholders.

1.5 SEC Key Performance Indicators (KPIs)

Following are the KPIs corresponding to this in-house intervention:

- **Relevance:** The study is meant to further the work done on materializing the SAARC Energy Ring (bilateral as well as multilateral power interconnections within and across South Asia) which is the very purpose of establishing the SEC. In addition, the outcome of the proposed study will help the Member States in strengthening their efforts towards a stable power grid.
- **Coherence:** Through the Action Plan FY 2015, SEC undertook an in-house study 'Harmonizing Transmission Grid Codes of SAARC Member States to Combat Regulatory Challenges for Intra-region Power Trading / Interconnections'. Capitalizing on that study, the currently proposed study is another step towards feeding the Member States to maintain a stable transmission grid and further move on towards regional connectivity for optimum use of indigenous resources and/or infrastructure.
- **Sustainability:** As mentioned earlier, the proposed activity is another step towards materializing the SAARC Energy Ring. It is believed that more of such interventions will be undertaken by the SEC in connection with establishing regional power interconnections while fine-tuning the SOPs for managing an efficient and stable power grid in South Asia.
- **Quality & Effectiveness:** As per SEC's practices, the study has been undertaken by the SEC professional team and to further add the value, it was peer reviewed by an external expert aiming to ensure the best possible quality and effectiveness thereof.
- **Participation:** Final report of the study, after incorporation of comments and suggestions by the Peer-Reviewer, will be shared with the Member States for their feedback as well as consideration for implementation. The report will be updated based on the comments and suggestions, if any, received from the Member States to ensure the ownership of the stakeholders i.e. the power transmission utilities of South Asia.

1.6 Methodology

SEC has undertaken this study as an in-house intervention with Program Leader (Energy Trade) responsible for accomplishing it. Data with respect to existing planning criteria of all the Member States, where available, was collected and studied. The same was assessed mutually as well as in the perspective of best practices. The Study output thus includes recommendations for incorporation in the individual planning criteria of the Member States. The draft report was finalized after the incorporation of comments and suggestions by the peer-reviewer, an external expert. The final report will be published and shared with the Member States for their comments, suggestions and consideration.

1.7 Important Definitions

In this section, various planning terms have been provided to share the knowledge aiming at improved understanding of the study relevant concept.

a. Deterministic Planning

The simplest planning problems involve finding a sequence of actions that lead from a given initial state to a goal state. Only deterministic actions are considered. Determinism and the uniqueness of the initial state mean that the state of the transition system after any sequence of actions is exactly predictable.

b. Probabilistic Planning

Probabilistic planning is an extension of nondeterministic planning with information on the probabilities of nondeterministic events. Probabilities are important in quantifying the costs and success probabilities of plans when the actions are nondeterministic.

In many applications, it is not sufficient just to have a plan. It is important to have a plan that is efficient in the sense that the cost of the actions does not outweigh the benefits of reaching the goals. On some other problems there are no plans that are guaranteed to reach the goals. In these cases it is important to maximize the probability of reaching the goals, and hence it is vitally important to use information on the probabilities of different effects of operators.

c. Low Flow Studies

In power engineering, the Power-flow Study, or Load-flow Study, is a numerical analysis of the flow of electric power in an interconnected system. A power-flow study usually uses simplified notations such as a one-line diagram and per-unit system and analyzes the power systems in normal steady-state operation.

Power-flow or Load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power-flow study is the magnitude and phase angle of the voltage at each bus, and the real and reactive power flowing in each line.

d. Short Circuit Analysis

A Short Circuit Analysis is used to determine the magnitude of short circuit current the system is capable of producing, and compares that magnitude with the interrupting rating of the overcurrent protective devices in the system.

e. Stability Analysis

When an interconnected system of generators experiences a fault, a protective device normally clears it within a specified timeframe. This creates a disturbance on the network which, in order to remain stable, must be able to absorb an amount of resulting energy. This transient energy moves the generators away from their equilibrium point (swing) and thusly converts itself into kinetic energy within the units. For the system to maintain its synchronicity, it must be able to absorb the transient energy while internal forces within the generators are trying to establish new equilibrium positions. If the system is unable to convert enough transient energy into potential energy, then there is a tendency for generator excitation controls to move erratically, failing to re-establish their original equilibrium point, yielding in the network becoming unstable.

Model Stability Analysis is therefore based on the premise that the system shall remain stable both within the transmission system and those systems directly connected to it subsequent to a fault or the loss of a vital system element, which is typically a generator or transmission circuit. Typically, the disturbances with the most impact on stability are 3-phase faults located on the high-side voltage bus at the generator. Swing curves are reviewed to reveal whether or not other generators (i.e. without the disturbance) will synchronize (i.e. remain "in-step" with each other) properly following the disturbance. If the system is to remain stable, the undisturbed generators will respond to the fault and in doing so will tend to increase the generation angles between pairs of machines. Once the maximum difference is obtained, then their angle differences decrease and become more in sync. If, on the other hand, the angle between any two machines increases without limit, then the system can be judged to be unstable.

Steady-State Stability

Steady-State Stability analysis determines the maximum amount of power transfer that can be maintained without disturbances while maintaining proper synchronization with generators both on and off the Power System. These generators should be operating at some steady equilibrium state.

Operation of the transmission system should not exceed the steady-state stability transfer limit which would result in unforced service discontinuities. System interconnections may be opened to maintain steady-state stability in a post contingency scenario on adjacent systems if necessary.

Dynamic Stability

Disturbances occurring on a system that result in small system state changes are considered to be small perturbations or disruptions in equilibrium. Load changes occurring in a random fashion can be thought of as an example of this type of disturbance. If such a perturbation is small enough so that nonlinear differential equations used to study system dynamics around the operating point can be linearized, such stability problems are known as dynamic stability studies.

When performing these studies frequency should be maintained without the shedding of load due to protective device activity in post single contingency scenarios. Under-frequency load shedding should be employed in maintaining frequency for post double-contingencies on the own and adjacent systems.

Transient Stability

Large transmission system disturbances are used when performing Transient Stability Studies. These types of disruptions in system equilibrium can occur as a result of the loss of a large generator unit, major transmission facility or a large load as well as the occurrence of faults.

Objective of undertaking this type of study is to ensure that all generating units remain in an equilibrium state and be in step (synchronous) with other units on the power system as well as those on connected networks even after a major disturbance. The worst case scenarios are 3 phase faults in close proximity to a generator's high voltage bus, however this fault is assumed to be cleared within 5 to 6 cycles.

There are several considerations that should be allowed when performing these types of studies.

- The effect of slow short circuit clearing as a consequence of improper relay operation. Critical clearing times should be determined for key circuit breakers.
- Occurrence of serious contingencies not only on the own power system, but also on adjacent power systems where a major contingency might involve the own power system or portions thereof in a cascading incident.
- Anticipated bias or power flow conditions imposed on the Power Transmission System as part of the interconnected grid.

f. Design Philosophy

The planning criteria are used to assess network capacity and determine the need for and timing of network reinforcement or re-configuration. Network reinforcement plans are then developed which will satisfy the planning criteria and environmental constraints.

g. Purpose of the Planning Criteria

The purpose of planning criteria is to help strike a balance between the user's need for a safe, secure, reliable, high quality electricity supply and the desire for this service to be provided at minimal cost.

The process to assess network capacity and the need for network reinforcement

Network capacity and the need for network reinforcement are assessed by comparing the planning criteria with network performance for:

- Increasing load levels
- Changing load demand patterns
- Particular load characteristics
- Reliability

h. Cost of unserved energy

It is the amount of energy required by the consumer that cannot be supplied. This value is required for economic analysis for the least-cost generation expansion plan.

i. Reliability

The degree of performance of elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by the frequency, duration and magnitude of adverse effects on the electric supply. Reliability can be addressed by considering two basic and functional aspects of the System i.e. Adequacy and Security.

- **Adequacy**

  A measure of the ability of the power system to supply the aggregate electric power and energy requirements of the customers within components ratings and voltage limits, taking into account planned and unplanned outages of system components.

Adequacy measures the capability of the power system to supply the load in all the steady states in which the power system may exist considering standards conditions.

- **Security**

  The ability of the electric systems to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

j. Power System Stability

The property of a power system, which enables it to remain in a state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium following a disturbance.

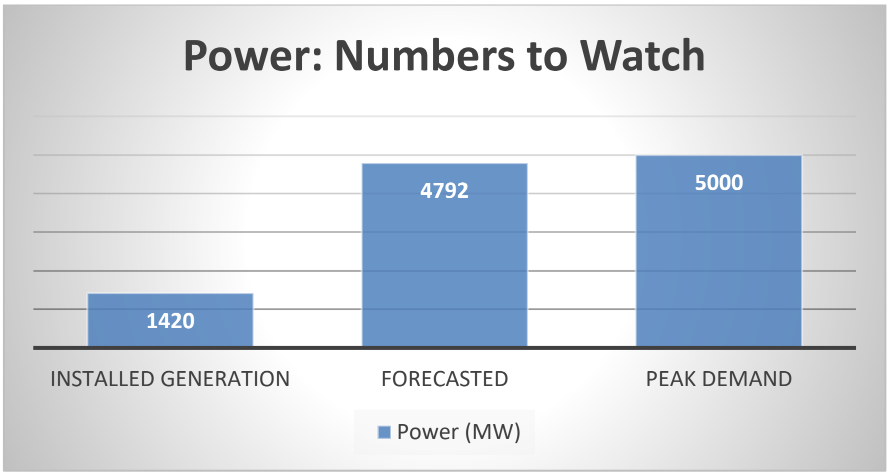
k. Energy Intensity

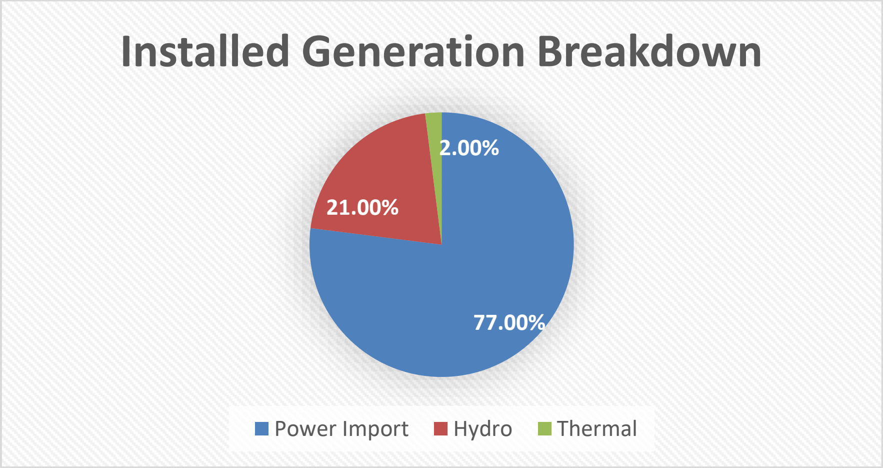
Energy intensity is a measure of the energy efficiency of a nation's economy. It is calculated as units of energy per unit of GDP. High energy intensities indicate a high price or cost of converting energy into GDP. Low energy intensity indicates a lower price or cost of converting energy into GDP. High energy intensity means high industrial output as a portion of the GDP. A low energy intensity signifies a labor-intensive economy.

2. Overview of Power Sectors of the SAARC Member States

2.1 Power Sectors of the SAARC Member States

2.1.1 Afghanistan





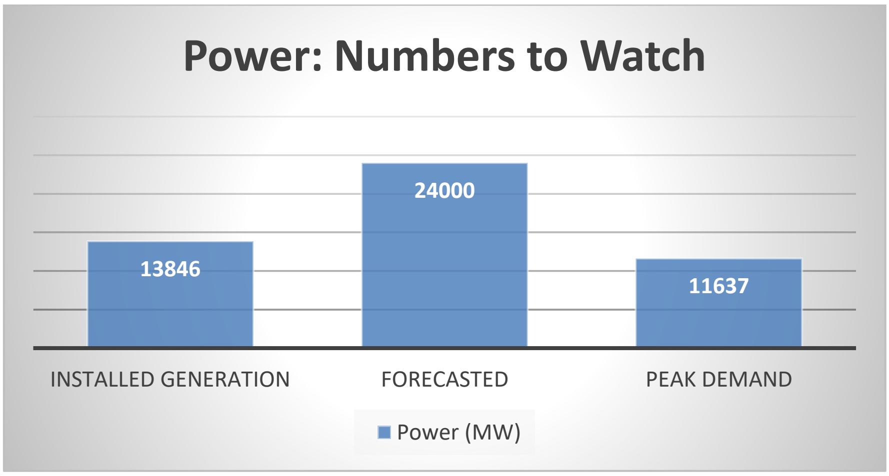
Installed Generation in 2014: 1,420 MW (2% Thermal, 21% Hydro, 77% Power Import)

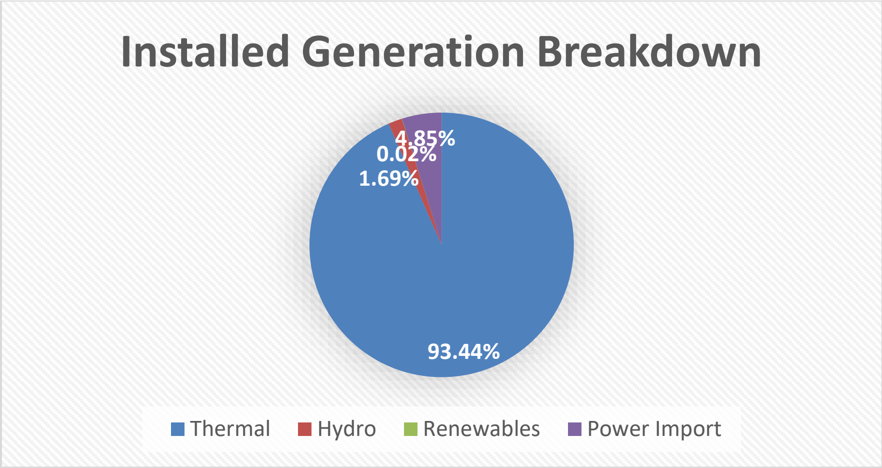
Peak Demand: 5,000 MW

Energy Generated (local power plants only): 590 mu

Forecasted Generation in 2020: 4,792 MW

2.1.2 Bangladesh





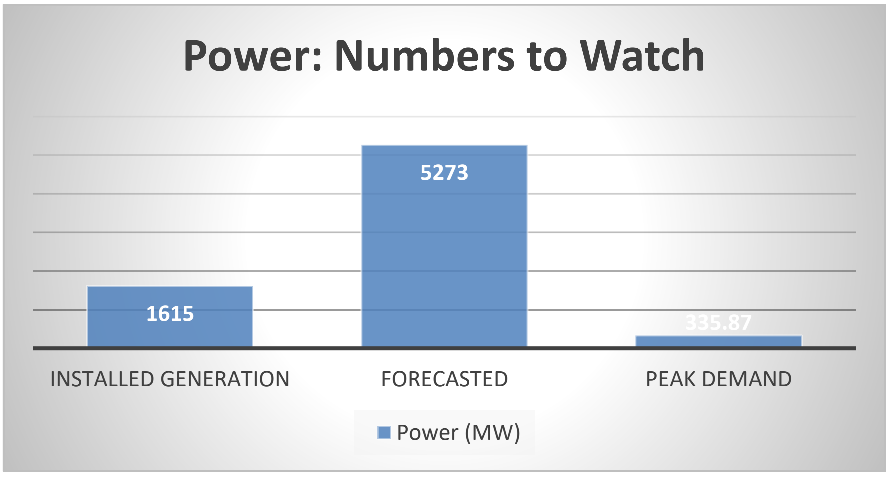
Installed Generation in 2017: 13,846 MW (93.45% Thermal, 1.69% Hydro, 0.02% Renewables, 4.85% Power Import)

Peak Demand: 11,637 MW

Energy Generated: 57,276 mu

(Forecasted) Installed Generation in 2021: 24,000 MW

2.1.3 Bhutan



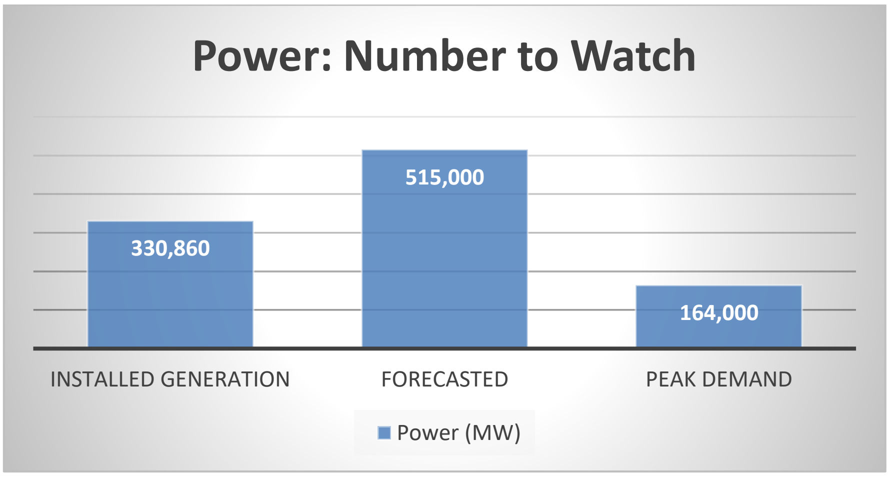
Installed Generation in 2017: 1,615 MW (100% Hydro)

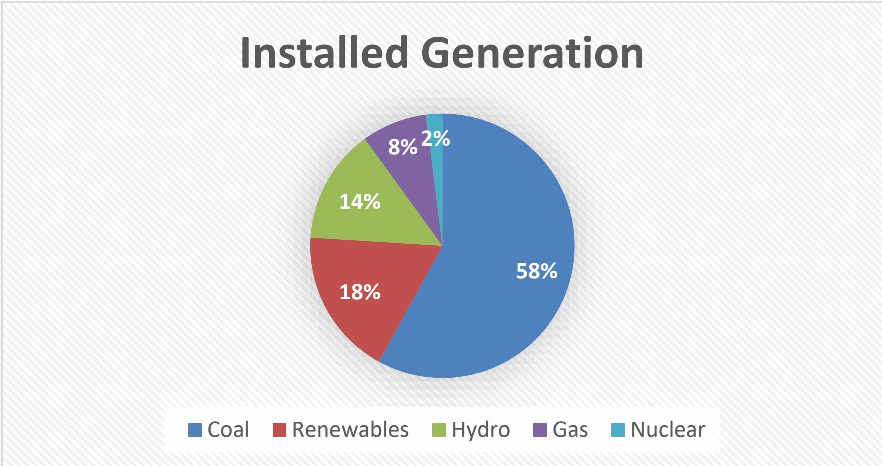
Peak Demand: 335.87 MW

Energy Generated: 7,864 million units

(Forecasted) Installed Generation in 2021: 5,273 MW

2.1.4 India





Installed Generation in 2016-17: 330,860 MW (58% Coal, 18% Renewables, 14% Hydro, 8% Gas, and 2% Nuclear)

Peak Demand: 164 GW

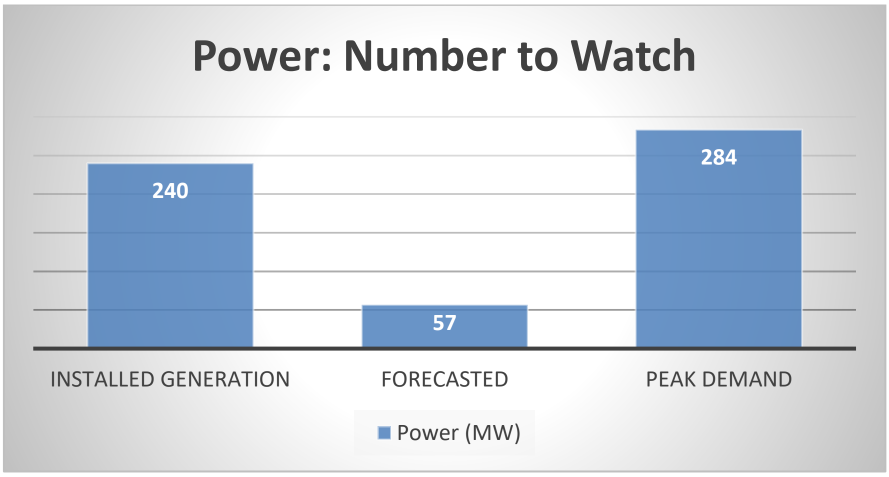
Energy Generated: 1,236,392.4 mu

(Forecasted) Installed Generation in 2021-22: 515,000 MW (52% Thermal, 34% Renewables, 12% Hydro and 2% Nuclear)

Transmission Line Length in November 2017: 381,671 km, expected to rise by 100,000 km in 2021-22

Transformer Capacity: 791,570 MVA, expected to rise by 215,000 MVA in 2021-22

2.1.5 Maldives



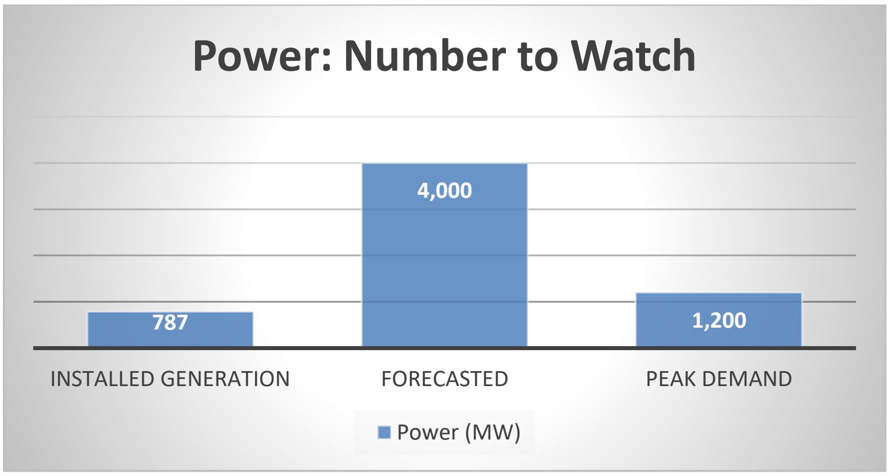
Installed Generation in 2015-16: 240 MW (100% Oil)

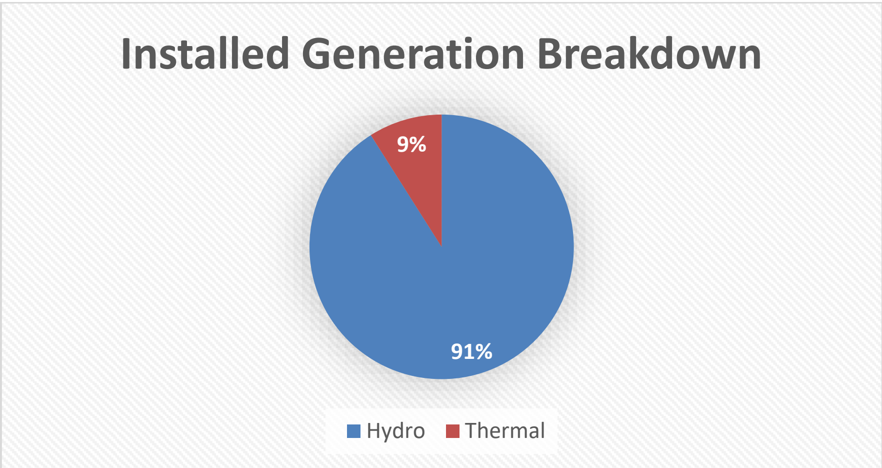
Peak Demand: 56.6 MW

Energy Generated: 330 mu

(Forecasted) Installed Generation in 2035: 366 MW (80% Thermal, 18% Renewables, and 2% Waste Heat)

2.1.6 Nepal





Installed Generation in 2015: 787 MW (9% Thermal, 91% Hydro)

Peak Demand: 1200.98 MW

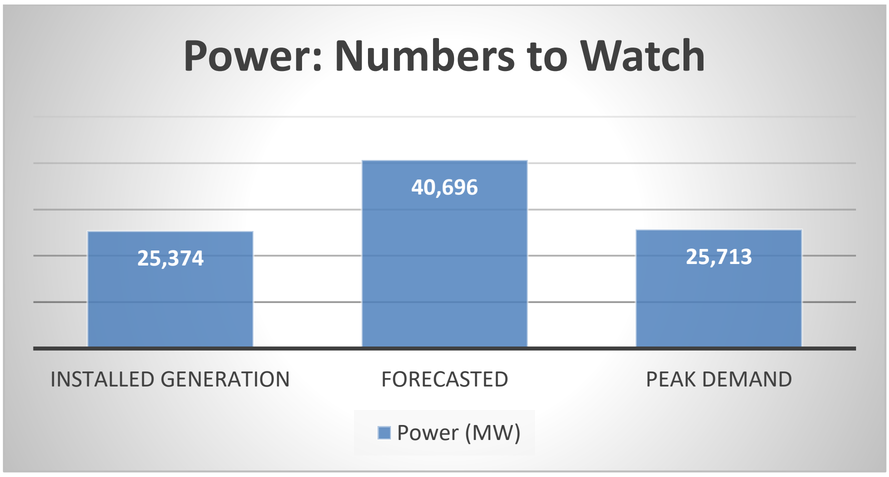
Energy Generated: 4,880 mu

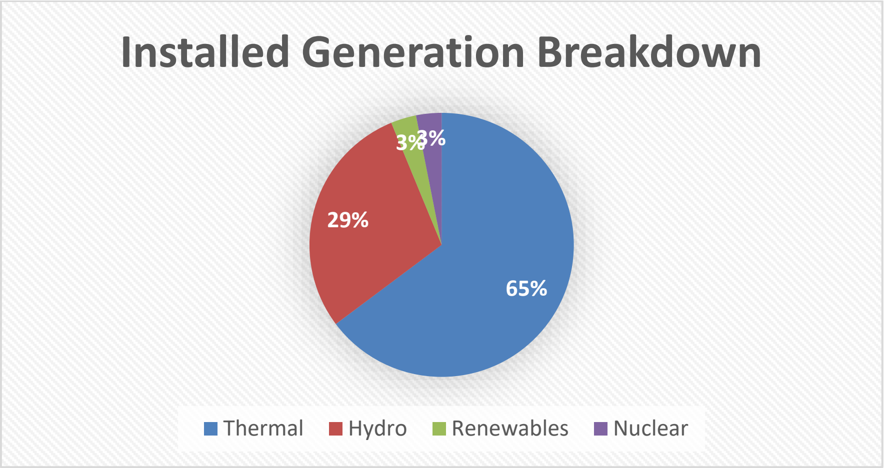
(Forecasted) Installed Generation in 2020: 3,268 MW

Transmission Line Length in November 2015: 2,130 km

Transformer Capacity: 1,722 MVA

2.1.7 Pakistan





Installed Generation in 2017: 25,374 MW (65.2% Thermal, 28% Hydro, 3% Renewables, 3% Nuclear)

Peak Demand: 25,713 MW

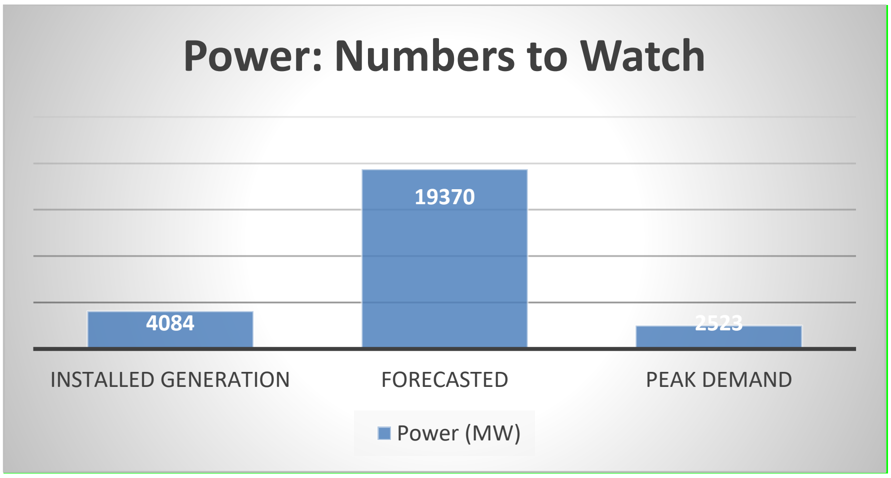
Energy Generated: 97,233 mu

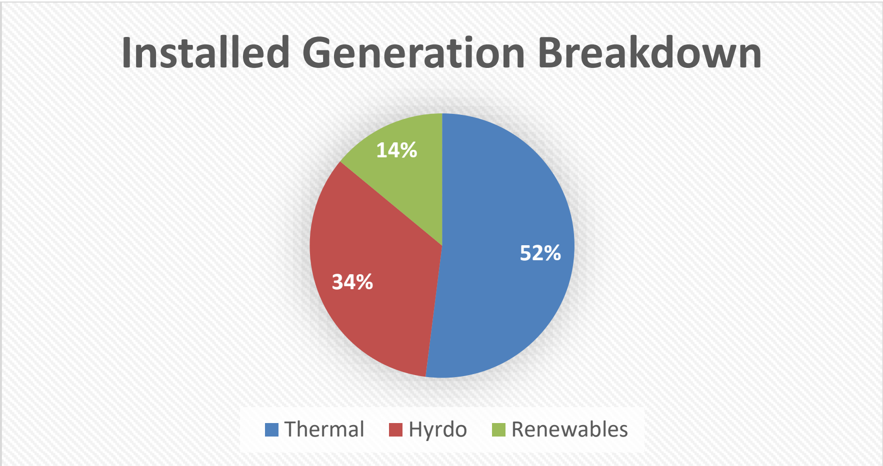
(Forecasted) Installed Generation in 2021: 40,696 MW

Transmission Line Length in 2016-17: 14,477 km, expected to rise by 5,584 km in 2021-22

Transformer Capacity: 46,587 MVA, expected to rise by 36,166 MVA in 2021-22

2.1.8 Sri Lanka





Installed Generation in 2017: 4,084 MW (52% Thermal, 34% Hydro, 14% Renewables)

Peak Demand: 2,523 MW

Energy Generated: 13,413 million units

(Forecasted) Installed Generation in 2021: 19,370 MW

Transmission Line Length in 2016-17: 2,913 km, expected to rise by 5,584 km in 2021-22

Transformer Capacity: 8,051 MVA, expected to rise by 36,166 MVA in 2021-22

2.2 Existing Cross Border Power Interconnections in the SAARC Region

Currently, cross border electricity interconnections exist, on bilateral basis and power trading agreements, between Bhutan-India, India-Nepal, India-Bangladesh, Iran-Pakistan. However, in view of the increasing awareness of the win-win situation, much is in the planning and development stage.

- The first major interconnection between Bhutan and India was commissioned in 1984 at 220 kV between Chukha (Bhutan)-Birpara (India/West Bengal). This was followed by a 400 kV interconnection with two 400 kV, double circuit, Tala (Bhutan) – Siliguri (West Bengal) lines. Currently, India is importing 1,500 MW from Bhutan, which is planned to be enhanced to 5,080 MW by the year 2022.
- Indo-Nepal Power Exchange began in year 1971 with exchange of about 5 MW of power on the principle of catering to the power needs of isolated local areas on both sides of

the border. The power export to Nepal was enhanced and took place on radial mode through a number of AC interconnections at 11 kV, 33 kV and 132 kV. Currently India is exporting power to India to the tune of 440 MW through radial and synchronous interconnections.

- In case of India-Bangladesh, first grid interconnection of 500 MW between Baharampur (India) - Bheramara (Bangladesh) through 400 kV double circuit link cross border link was commissioned in October 2013. By 2018 end, its capacity is planned to be doubled to 1,000 MW. Second grid interconnection between Tripura (India) - Comilla (Bangladesh) has facilitated a further 160 MW (100 + 60 MW) which is planned to be enhanced to 340 MW by 2021.
- Interconnection of India with Sri Lanka of 1,000 MW is on the drawing board, which includes submarine interconnection.
- The evolution towards interconnection with Central Asia is also on the way since Afghanistan is being connected to Pakistan and India, and through India to Nepal, Bhutan, Bangladesh and Sri Lanka.

With the commissioning of the above highlighted interconnections, the evolution of SAARC Energy Ring has been initiated and in fact achieved great progress with India being at a central position in the region and already connected with Nepal, Bhutan and Bangladesh.

2.3 Rationale for Cross Border Grid Interconnection in South Asia

Within South Asia, availabilities of the different generation sources and the demand in the different Member States show considerable daily as well as seasonal variations due to time difference, summer and monsoon season, working days/holidays, etc. It is an established fact that the total demand for electric energy in a country depends on factors such as the extent of electrification/access, industrialization, standard of living, population, climate, energy prices, etc.

Economy of a country is significantly affected if the total available generation is unable to meet either the peak power demand or the total energy demand of a country. Continuing generation additions to match the ever-increasing power demand of a country is a capital intensive process which is influenced by policies, institutional and regulatory frameworks and political environment in general. Therefore, for a generation deficient country, economically feasible solution to meet the demand in the short to medium term perspectives is to import power from neighboring country by establishing a cross-border transmission link and corresponding agreement. For a generation surplus country, cross-border transmission links and agreements is a source for earning revenues by exporting power and will further facilitate tapping of the remaining generation potential. Many cross-border links between US and Canada, Scandinavian countries and Europe are of this nature.

2.4 Planning Guidelines with respect to Development of Regional Plan

Based on the overall intent of the Article 7 of the SAARC Framework Agreement for Energy Cooperation (Electricity) as regard to planning of cross border interconnections, a consolidated Regional Plan is vital and required to be prepared in respect of each of the cross border links between the Member States. The Regional Plan can be for bilateral transactions or multilateral transactions, however, eventually it should cover the interconnections of entire SAARC region. Further, the Regional Plan should cover a horizon of next 10 to 20 years.

Based on the existing feasibilities, cross border interconnections anticipated within the SAARC Region are provided in the following Table.

Table 2.1: Potential Cross Border Inter-connections among the SAARC Member States

Interconnection	Member States
AC interconnection: 400 kV and above	• Between India & Bhutan, India & Nepal, India & Bangladesh • Between Pakistan & Afghanistan
AC interconnection of 220 kV and below (on radial mode)	• Between India & Bhutan, India & Nepal, India & Bangladesh • Between Pakistan & Afghanistan
HVDC back to back and Bi-pole	• Between India & Bangladesh • Between India & Pakistan
HVDC with underground cable Transmission	• Between India & Sri Lanka • Between Sri Lanka & Maldives (at a later date with due considerations on economics)

For preparation of an integrated Regional Plan, following may be considered as planning guidelines:

a. Scope of the plan would be macro level transmission planning for cross border trading considering 400 kV and above network in connected countries for next 10 or 20 years.

b. This shall include existing and future export and import agreements between the Member States.

c. The Regional Plan (covering both generation and transmission expansion) also shall include feasibility studies for future years with various possible scenarios.

d. Planned cross border link shall satisfy N-1 contingency for HVDC links and N-1-1 for AC interconnection.

3. Review of the Existing Planning Criteria of the SAARC Member States

3.1 Transmission Planning Process for the SAARC Member States

Pursuant to the relevant local laws and regulations, different entities of the SAARC Member States are responsible for taking care of their corresponding transmission planning process. Brief description in respect of each Member State is as follows:

3.1.1 Member State Bangladesh

Government of Bangladesh is mandated to authorize a system planner for preparing and submitting a long term, preferably 20 years, Power System Master Plan covering transmission and generation expansion, to the Bangladesh Electric Regulatory Commission (BERC). This plan is updated periodically, preferably every 5 years and is used as an input to the overall national plan.

3.1.2 Member State Bhutan

The System Operator prepares medium term (5 years) as well as long-term (10 years) load forecasts for the overall country system. Based on the prepared load forecast, System Operator also prepares a medium term expansion plan for the generation capacity. Subsequently, Ministry of Economic Affairs develops and periodically updates the overall Power System Master Plan that covers corresponding developments for the transmission system which includes and dominates with export transmission facilities. Considering the prepared plan, the transmission licensee undertakes grid planning studies and prepares a transmission plan which is ultimately submitted to Bhutan Electricity Authority for approval.

3.1.3 Member State India

Central Electricity Authority formulates the perspective transmission plan every five years and continuously updates to effect the updated load forecasts and new generation scenarios. CEA is also mandated to manage the load forecast. In view of the established competitive power market in India, the only country to achieve this landmark in South Asia, transmission licensee is responsible to provide the non-discriminatory open access for all inter-state transmission lines whereas state transmission utilities are mandated to provide the same for intra transmission lines. Further, all other transmission licensees are also required to provide open access.

3.1.4 Member State Nepal

Nepal Electricity Authority – the electricity utility is responsible for grid planning. Relevant data is collected from the distribution utilities and other grid users. A demand forecast for 15 years is prepared each year followed by a least cost generation plan. Based on the prepared demand forecasts and thereof the generation expansion plan, the utility is also responsible for conducting grid performance review each year with a planning horizon of five years. All these efforts are integrated every year to review the Power System Master Plan.

3.1.5 Member State Pakistan

National Transmission and Dispatch Company Limited, owner and operator of the national grid undertakes the planning process to develop a Transmission System Expansion Plan, which is submitted to the regulator, National Electric Power Regulatory Authority each year as part of the "Annual System Reliability Assessment and Improvement Report". This plan is prepared for next 1, 3, 5 and 10 years. The plan starts with a long-term load forecast of at least for twenty years, covers generation expansion and includes the required transmission system expansion projects.

3.1.6 Member State Sri Lanka

Transmission Licensee is mandated to prepare the transmission development plan for a period of ten years which is updated at least once in two years.

3.2 Planning Criteria of the Member States as Regulatory Requirement

Transmission Planning Criteria is provided in the respective Grid Codes in case of the SAARC Member States, where available as detailed in the following data table. However, in case of Member State India, Planning Criteria is briefly explained in the Grid Code and it has been provided in detail in Transmission Planning Criteria notified by Central Electricity Authority in January 2013.

Table 3.1: Planning Criteria as Regulatory Requirement for the SAARC Member States

Member State	Grid Code Section
Bangladesh	4.4
Bhutan	4.6
India	3.5, Central Electricity Authority (CEA) Transmission Planning Criteria
Nepal	3.6
Pakistan	PC 2.2
Sri Lanka	2.5

3.3 Salient Features of the Planning Criteria of the Member States

For all the Member States, N-1 contingency criteria is applicable. However, it is to be noted that in case of Member State India, outage of single circuit at 400 kV and 765 kV levels and outage of double circuit at 132 kV and 220 kV levels is considered as ‘N-1’ (which remain more stringent) outage whereas in case of other Grid Codes, at all transmission voltage levels, outage of single circuit is considered. Member State India also provides N-1-1 stability criterion for critical elements of the grid which proves their code as more stringent.

Planning Criteria of Member States Bhutan, India and Sri Lanka include that transmission system should be capable of withstanding loss of most severe single system in-feed (India and Bhutan) or loss of one generator (Sri Lanka) whereas the Planning Criteria of remaining Member States do not include the regulations pertaining to loss of in-feed or generator.

There is another exclusive feature of Planning Criteria in case of Member State India; it specifies a planning margin to be considered during planning stage hence voltage variation limits vary for planning and operation stages.

3.4 Transient Stability Limits for all the SAARC Member States

Transient stability limits as provided in the Planning Criteria of all the Member States are as follows:

a. **Member State Bangladesh:** Grid planning studies are undertaken aiming to maintain the system stable during a temporary fault clearance by three-phase trip within 100 ms and followed by successful re-closure within 300 ms. From stability perspective, the maximum fault clearance times shall be 100 ms for 400 kV and 160 ms for 220 and 132 kV faults.

b. **Member State Bhutan:** Planning Criteria does not specify any limits, however, it highlights that transient stability should be considered in planning studies.

c. **Member State India:** Transmission grid is meant to plan to survive the following:

   - A permanent 3-phase to ground fault on 765 kV or 400 kV cleared in 100 ms.
   - A permanent 3-phase to ground fault on 220 kV or 132 kV cleared in 160 ms.
   - A permanent 1-phase to ground fault on a 765 or 400 kV and accordingly, single pole opening (100 ms) of the faulted phase and unsuccessful re-closure (dead time 1 second) followed by 3-pole opening (100 ms) of the faulted line shall be considered.
   - A fault in HVDC convertor station, resulting in permanent outage of one of the poles of HVDC Bi-pole.
   - An outage of single largest generating unit or a critical generating unit.
   - A temporary 1-phase to ground fault on a 765 kV in a scenario where a N-1 contingency has already happened in the system. Accordingly, single pole opening (100 ms) of the faulted phase and successful re-closure (dead time 1 second) shall be considered.
   - In India, Transmission licensee is responsible to perform the reactive power compensation studies for Inter State Transmission System.

d. **Member State Nepal:** Nepalese Planning Criteria, like that of Bhutanese, only specifies that transient stability shall be considered in planning studies and does not mention any specific limits.

e. **Member State Pakistan: Planning Criteria** regulates that planning process should consider that system be capable of surviving a permanent 3-phase to ground fault on 500 kV or 220 kV with a fault clearance of 100 ms.

3.5 Important Standards included in Planning Criteria of Member States

In order to highlight a comparison of important standards provided in the Grid Codes of the SAARC Member States indicating their priorities with respect to developing and operating the power grid is provided in this section.

Member State Bangladesh

Sr. No.	Dimension	Parameter
1.	Contingency Checks	Contingency conditions applicable for transmission system total or partial blackout.
2.	Base Cases Available	The organization assigned by the government time to time, termed as System Planner, will prepare and submit a long-term (preferably 20 years which may be termed as planning-term)
3.	Steady State Performance Monitoring	
4.	Normal Operation	
5.	N-1 Contingency Check	
6.	Transmission Planning Procedure	System studies shall be carried out for the improvement of power system.
7.	Load flow studies	Load flow studies (peak and off peak loads for maximum hydro and maximum thermal generation).
8.	System Reliability Evaluation	The Commission shall prescribe a reliability index that will measure the total number of sustained power interruptions in the Grid.
9.	Outage Limits and Statistics	Thermal ratings shall be considered for normal and emergency conditions
10	Transient Stability Analysis	To be maintained stable during a temporary fault clearance by 3-phase trip within 5 cycles

Sr. No.	Dimension	Parameter
11.	System Parameter Limits	Thermal ratings shall be defined and should meet the installed capacity target demands.
12.	Voltage Limits - Contingency Condition	Voltage limits at 132 kV, 230 kV and 400 kV bus (±10% during emergencies and ±5% during normal conditions)
13.	Short Circuit Analysis	Short circuit calculations shall be made and protection measures will be carried out for this purpose

Member State India

Sr. No.	Dimension	Parameter
1.	Contingency Checks	N-0, N-1 and N-1-1 contingency conditions
2.	Base Cases Available	Preparation of base case models corresponding to load generation scenarios for 5-year horizon.
3.	Steady State Performance Monitoring	All parameters such as voltages, loadings, frequency should remain within permissible limits in steady state and transient behavior
4.	Normal Operation	Normal operation (N-0) condition in which all parameters should remain within permissible limits
5.	N-1 Contingency Check	Emergency or most probable disturbance for N-1 condition.
6.	Transmission Planning Procedure	System studies for firming up the transmission plans may be carried out with 3-5 years
7.	Load flow studies	Load flow studies for calculations, planning future expansions and essential for designing a new power system
8.	System Reliability Evaluation	System tested for all load generation scenarios under N-0 and N-1 condition for reliability
9.	Outage Limits and Statistics	Thermal and voltage ratings for normal and emergency conditions.

Sr. No.	Dimension	Parameter
10.	Transient Stability Analysis	Transient stability studies for the removal of perturbations.
11.	System Parameter Limits	Thermal loading limits for line and transformer to be 10% and 15% for inter-regional
12.	Voltage Limits - Contingency Condition	Margin of ±2% kept in voltage limits for N-0 and N-1 conditions
13.	Short Circuit Analysis	Short circuit studies to be carried out in classical method, fault and pre-fault voltages and sub transient reactance of synchronous machines
14.		**Guidelines:**
		Reactive power Compensation
		Shunt Capacitors (<132 kV / 220 kV Voltage Level)
		Shunt Reactors (only 5% change)
		Static VAR Compensation (Not under steady state as far as possible)
		Sub-station Planning Criteria (<80 % of rated short circuit capacity)
		Additional Criteria for Wind and Solar Projects (Maintain a power factor of 0.98)

Sr. No.	Dimension	Parameter
		Additional Criteria for Nuclear Power Stations (Two independent sources of power supply at 10 ◦ C)
		Criteria for HDVC Transmission System (>2000 MW over 700 km (AC LINES AT > 5000 MW))
		Voltage Stability (Load Flow Analysis Program)

Member State Pakistan

Sr. No.	Dimension	Parameter
1.	Contingency Checks	N-0 and N-1 contingency conditions.
2.	Base Cases Available	Two base case scenarios for each year.
3.	Steady State Performance Monitoring	Steady state system performance depends upon equipment loading, congestion management, fault levels and voltage regulation.
4.	Normal Operation	Normal continuous maximum ratings for N-0 condition in steady state.
5.	N-1 Contingency Check	Emergency ratings for N-1 contingency condition in steady state.
6.	Transmission Planning Procedure	Steady state load flow studies shall be made to define the congestion conditions.
7.	Load flow studies	Load flow studies for the elimination of congestion conditions.
8.	System Reliability Evaluation	Evaluation of the reliability of transmission system components shall be determined according to outage statistics.
9.	Outage Limits and Statistics	Outage statistics shall be based on frequency of failure and time duration to make repairs.
10.	Transient Stability Analysis	Transient stability studies shall be made for the fault conditions.
11.	System Parameter Limits	Under normal condition N-0, all bus voltages shall be within the bandwidth of +5% to -5% of Nominal System Voltage.

Sr. No.	Dimension	Parameter
12.	Voltage Limits - Contingency Condition	Under contingency condition N-1, all bus voltages shall be within the bandwidth of ±10% of Nominal System Voltage.
13.	Short Circuit Analysis	Short circuit calculations shall be prepared for each year.

Member State Sri Lanka

Sr. No.	Dimension	Parameter
1.	Contingency Checks	
2.	Base Cases Available	
3.	Steady State Performance Monitoring	
4.	Normal Operation	
5.	N-1 Contingency Check	
6.	Transmission Planning Procedure	Steady state stability studies shall be carried out and will advise the grid users on the installation of power system stabilizers.
7.	Load flow studies	Load flow studies on the Transmission System shall be carried out for every year for a planning window of 10 years.
8.	System Reliability Evaluation	The Transmission Licensee shall perform studies to determine the frequency and duration of interruptions in the Transmission System.
9.	Outage Limits and Statistics	
10.	Transient Stability Analysis	Transient stability studies shall be carried out for single outage contingency of critical transmission system components for forecast maximum and minimum load conditions.

Sr. No.	Dimension	Parameter
11.	System Parameter Limits	All individual circuit elements of the transmission system have at least two thermal ratings in terms of load carrying capacities.
12.	Voltage Limits - Contingency Condition	
13.	Short Circuit Analysis	Short circuit studies shall be carried out for each year in the planning window, to forecast three-phase maximum and minimum fault levels and single-phase fault levels, for all system nodes.

4. Review of Existing Planning Criteria of Countries beyond South Asia

For the purpose of this study, it was found necessary to review the approach adopted in other countries. The reliability criteria used in North America (USA and Canada), Nordic countries (Denmark, Finland, Norway and Sweden), Britain, Australia, Japan, Ireland and South Africa were reviewed and are discussed in this section. Details of the criteria along with a tabulated summary covering all the countries mentioned above are given in this section.

During the last few years, extensive deregulation has been underway in these countries. This may result in some aspects of the criteria presented in this section to be modified or re-interpreted.

4.1 North America

The planning standards used by the North American Reliability Council (NERC) apply to the bulk electric systems of the U.S. and Canada (110 kV and above). Table provides a definition for the four categories of system events that is taken into consideration and the acceptable response to these events. A description for the four categories is given below.

a. **Category A: System Intact**

This represents a normal system operation with no contingencies and all facilities in service. The system must supply all firm load and firm transfers to other areas. All equipment must operate within applicable thermal and voltage ratings. The system must be stable with no cascading outages.

b. **Category B: N-1 Contingencies**

This covers the loss of any single element under specified fault conditions and normal clearing. Single elements are generator, transmission circuit, transformer, single pole of DC transmission line. This is often referred to as N-1 event or with the most critical generator out of service, an N-G-1 event. The acceptable impact on the system is the same as Category A. Radial customers, including loads or generators, are allowed to disconnect from the system.

c. **Category C: Multiple Contingencies**

This covers the loss of one or more of system elements under specified fault conditions and include both normal and delayed fault clearing events e.g. bus section, breaker failure, bipolar DC line, two circuits of a multiple circuit tower line etc. When two specified system elements are lost simultaneously, this is often referred to as an N-2 event. All of the system limits for Category A and B events apply with the exception that planned, controlled loss of either firm load, firm transfers and/or certain generation are acceptable provided there is no cascading.

e. **Category D: Extreme Contingencies**

This covers a wide variety of extreme and rare unpredictable events which may result in the loss of customer demand (firm load) and generation in wide spread areas. Such events include loss of tower line with three or more circuits, all transmission lines in a common corridor, loss of a substation (one voltage level plus transformers), loss of power plant, loss of major load center, failure of a fully redundant SPS to operate when required, etc. The system may not be able to reach a new stable state. Events of Category D need to be evaluated for risk and consequences.

Table 4.1: NERC Transmission Standards – Normal and Emergency Conditions

Category	Contingency	System Impacts and Limits
A : No contingences	All facilities in service	System stable, customer demands must be met within applicable voltage and thermal ratings (1)
B : Event resulting in the loss of a single element with normal clearing	- Generator - Transmission circuit - Transformer - Single pole (dc) line	- Acceptable impact same as for Category A. - Radial customers including loads or generators are allowed to disconnect
C : Event(s) resulting in the loss of two or more (multiple) elements with normal clearing	- Bus section - Breaker failure - Loss of single element followed by manual system adjustment and the loss of another single element - bipolar (dc) line - double circuit tower line	All system limits of Category A and B events apply with the exception that controlled loss of either firm load, firm transfers, and/or certain generation are acceptable provided there is no cascading
D: Extreme events resulting in two or more (multiple) components removed or cascaded out of service	- single element (three phase fault with delayed clearing) - loss of substation - loss of all transmission lines in a common corridor - loss of a power plant	May result in loss of customer demand and generation in widespread areas. System may not be able to reach a new stable state. These events need to be evaluated for risks and consequences

(1) Applicable rating refers to the applicable normal and emergency facility thermal rating or system voltage limit as determined and consistently applied by the system or facility owner. Applicable rating may include emergency ratings applicable for short durations as required to permit operating steps necessary to maintain system control.

4.2 Nordic Countries

The Nordel grid comprises the national electric power systems of Denmark, Finland, Norway and Sweden. The objective of the Nordel transmission planning criteria is to provide a common minimum reliability for all parts of the Nordel transmission system and to limit the risk of uncontrolled disturbances in the interconnected system. This concerns principally the main grid, mainly 220-400 kV and the interconnection links between the various countries.

The basic requirement of the Nordel criteria is that the interconnected system must withstand an N-1 event both on the interconnection and in the connected grids without limitations due to thermal conditions, voltage stability or dynamic stability. More serious consequences are acceptable for less common combinations of faults and operating conditions. The criteria are based on a balance between the probability of faults and their consequences i.e. more serious consequences may be acceptable for faults with lower probability. The criteria are defined based on five types of faults. These fault types can be grouped into the following two main categories.

N-1 Faults

a. Common single faults:

- Generation unit, transformer, transmission circuit
- Load block with associated transformer
- Shunt component (capacitor, reactor)
- DC pole
- Bus section
- Other series components (series capacitor, etc.)

b. Less common single faults and special, more frequent, combinations of two simultaneous faults (2-phase or 3-phase):

- Transmission line, one circuit (without fast auto-reclose)
- Bus bar (for stations that are of importance to joint operation between countries)

c. Permissible consequences for N-1 faults:

For the common single faults and apart from load shedding or tripping of generation that is necessary for eliminating the fault, limited amount of loads and generation may be switched out by automatic control equipment.

For the less common faults, controlled forced tripping of generation and loads is allowed. Minor grid breakdowns are also allowed provided that they are restricted to the region (part of a national grid) in which the fault has occurred.

Serious Faults

a. Combinations of two simultaneous faults with a common cause involving 3-phase faults:

- combination of line fault and loss of a thermal unit
- double circuit transmission line

- stuck breaker pole or relay fault
- two generating units
- DC bi-pole link
- Two transmission lines along the same cleared path

b. Other multiple faults

- Two independent simultaneous faults
- Three or more independent simultaneous faults

c. Permissible consequences for serious faults:

For simultaneous faults with common cause, controlled forced tripping of generation and loads is allowed. Minor grid breakdowns are also allowed provided that they are restricted to the region (part of a national grid) in which the fault has occurred. For two or more simultaneous independent faults, instability is acceptable which could be followed by grid sectionalization and extensive breakdown.

4.3 Britain

The planning criteria adopted by the operator of the transmission system in Britain (National Grid Company) differentiate between the supply points feeding the load (Demand Groups) and the Main Interconnected Transmission System (MITS), which connects these supply points to the generation sources. The Demand Group is defined as a site or group of sites which collectively take power from the remainder of the transmission system while the Main Interconnected Transmission System (MITS) consists of all 400 kV and 275 kV elements of the transmission system. Assessment of the reliability of supply to Demand Groups and the reliability of the MITS are based on the following contingency criteria.

Demand Groups

Contingencies considered include fault outage of a single transmission circuit during peak conditions (transformer, reactor, cable, and overhead line but excludes bus bars and generation units).

Main Interconnected Transmission System (MITS)

Contingencies considered include fault outage of a single transmission circuit, a double circuit overhead line, a section of bus bar or mesh corner or a single transmission circuit with the prior outage of another transmission circuit or a generating unit.

Acceptable Consequences

In the event of the above-mentioned contingences, there shall not be any of the following (for both the Demand Groups and the MITS):

i. Loss of supply capacity (except as permitted by the demand connection criteria)

ii. Unacceptable overloading of any primary transmission equipment

iii. Unacceptable voltage conditions or insufficient voltage performance margin

iv. System instability.

Table 4.2: Britain - Minimum Planning Supply Capacity Following Fault Outages

<table>
<tr><td rowspan="2">Group Demand</td><td colspan="2">Initial system conditions</td></tr>
<tr><td>Intact system</td><td>With single planned outage
The planned outage may be of a transmission circuit, generating unit, reactive compensator or other reactive power provider.</td></tr>
<tr><td>Over 1500 MW</td><td>Immediately
Group Demand</td><td>Immediately
Group Demand</td></tr>
<tr><td>Over 300 MW to 1,500 MW</td><td>Immediately
Group Demand
Up to 60 MW may be lost for up to 60 seconds if this leads to significant economies.</td><td>Immediately
Maintenance Period Demand
Within time to restore planned outage
Group Demand</td></tr>
<tr><td>Over 60 MW to 300 MW</td><td>Immediately
Group Demand – 20 MW
The group demand may be lost for up to 60 seconds if this leads to significant economies
Within 3 hours
Group Demand</td><td>Nil</td></tr>
<tr><td>Over 12 MW to 60 MW</td><td>Within 15 minutes
Smaller of (Group Demand minus 12 MW) and two thirds of Group Demand
Within 3 hours
Group Demand</td><td>Nil</td></tr>
<tr><td>Over 1 MW to 12 MW</td><td>Within 3 hours
Group Demand minus 1 MW
In repair time
Group Demand</td><td>Nil</td></tr>
<tr><td>Up to 1 MW</td><td>In repair time
Group Demand</td><td>Nil</td></tr>
</table>

4.4 Australia

The Australian planning standards are based on the following contingency types and conditions.

Single credible contingency event

It is a contingency event the occurrence of which is considered to be reasonably possible e.g. the loss of a generating unit or a transmission plant (transmission line, transformer or a reactive plant) other than as a result of a three phase fault anywhere in the power system. The system is expected to survive this type of faults without disruption to power system security.

Critical single credible contingency event

It includes the instantaneous loss of the largest generating unit on the power system or the loss of any interconnection under abnormal conditions. This type of contingency is expected to have the potential for the most significant impact on the power system.

Non-credible contingency event

This is defined as a contingency event other than a credible contingency event. Examples of non-credible contingency events are likely to include:

a. three phase faults on the power system or
b. simultaneous disruptive events such as:
   - multiple generating unit failures or,
   - double circuit transmission line failure (such as may be caused by a tower collapse).

Acceptable Impact

a. Contingency considered: Following a contingency event (whether credible contingency event or not) or a significant change in power system conditions, all reasonable actions should be taken to adjust the operating conditions with a view to returning the operating system to a secure operating state within 30 minutes.
b. Adequate load shedding facilities should be available to restore the system to a satisfactory operating state following significant multiple contingency event.
c. The limits of the operation of the power system associated with the avoidance of voltage failure or collapse must be assessed under credible contingency event scenarios. These limits must be translated into key location operational voltage settings or limits, transmission line capacity limits, reactive power limits to enable their use in the maintenance of power system security.
d. The system should remain in synchronism and maintain:
   - Transient stability following any single credible contingency event which includes the application of a fault (other than a three phase fault), cleared by primary protection time, to any part of the power system
   - Oscillatory stability in the absence of any contingency event for any level of inter-regional or intra-regional power transfer up to the applicable operational limits.

- The halving time of any inter-regional or intra-regional oscillation, i.e. the time for the amplitude of an oscillation to reduce to half, should be less than 10 seconds. To allow for planning and operational uncertainties, the power system should be planned and operated to achieve a halving time of 5 seconds.
- Voltage stability following the most severe contingency event.

4.5 Japan

The transmission planning criteria calls for system development plans to be prepared such that system security is met with all facilities in service and during abnormal conditions (N-1 and N-2 contingencies) taking into account the frequency and influence of power system contingencies.

All facilities in service

a. Power flow does not exceed the continuous rated capacity of the facilities such as transmission lines and transformers.
b. System voltage is maintained properly within the targeted range.
c. Stable operation of generators

N-1 Contingency

The N-1 contingency includes the outage of a single circuit, transformer and a generator. Blackouts should not occur in principle in the event of N-1 contingency, but may be permitted if their influences are small enough. Blackouts must be avoided as much as possible for the areas with large social impact i.e. the areas of high load density. The blackouts due to N-1 contingency on the trunk transmission lines must be avoided as much as possible.

Power flows should be kept under the overloaded capacity for a limited period of time in the event of a single contingency of parallel operating facilities.

N-2 Contingency

N-2 contingency includes simultaneous loss of two or more facilities such as the loss of two circuits of a transmission line.

Partial outage of generation and supply can be permitted in case of N-2 contingency as these rarely occur.

Acceptable Dynamic Impact

a. Stability Assessment

In principle, power systems must remain stable in the event of a three-phase fault with normal clearing. Assumed contingencies shown below may also be assessed by taking into account the power system configuration and the probability of contingencies.

- Simultaneous single phase to ground fault on two circuits cleared by primary protection – re-closing.
- Simultaneous two phase to ground fault on two circuits cleared by primary protection – re-closing.
- Delayed clearing (failure to operate primary protection)

- Bus fault
- Loss of tower line

b. Voltage stability assessment

An abnormal drop in the system voltage could lead to system collapse and large-scale blackouts. Therefore, the voltage must be kept stable to prevent such a phenomena.

Voltage stability is assessed assuming an N-1 contingency in principle. Voltage stability is also assessed for contingencies such as loss of a tower line in the loop system after taking into account power system configurations.

4.6 Ireland

The transmission grid (110, 220 and 400 kV) in Ireland is owned by the Electricity Supply Board (ESB) and operated by an independent system operator (EirGrid) which also plans and develop the system. This arrangement was effective as from July 1, 2006. Prior to that ESB was responsible for operating as well as planning and developing the system.

The transmission planning criteria used by ESB is summarized on Table. The criteria divide the system disturbances into two categories: More Probable Contingencies and Less Probable Contingencies. A brief description is given below for both categories.

More Probable Contingencies

a. N-1 and N-G-1

Following an outage, the system should not be in voltage collapse or experience cascade tripping. Voltage and thermal loading should be within emergency limits. Within the time for which emergency limits are valid, the system should be able to return to normal limits by means of control actions such as operator actuated or automatic tap changing, shunt element switching, generation dispatch, etc.

b. Trip-Maintenance N-1-1

The trip-maintenance case includes the forced outage of a transmission element or generating element while another element is out on maintenance. It also includes the overlapping forced outage of two elements at a time, where there is sufficient period between the first and second outage to allow for adjustment back to normal operation.

Some loss of load is allowed for trip- maintenance events as their occurrence is much less than single contingency events.

Less Probable Contingencies

For system integrity, the system should be able to withstand more severe but less probable contingences without going into voltage collapse or uncontrolled cascading outages.

Examples of this class of outages are bus bar faults, bus bar coupler faults, breaker failure, relay mal-operation, loss of double circuit line, etc.

Table 4.3: ESB (Ireland) Contingency Criteria

Disturbance	Analysis	Criteria	Allowable Remedial Actions
Base Case			
None	Steady state load flow	Normal limits Capacitor switching Voltage step	Tap-changing, Phase angle regulators, Switched shunts, Bus bar sectionalizing
	Short circuit analysis	Allowable short circuit levels	None
More Probable Contingencies			
Single Contingency (N-1)			
• Line • Transformer • Generator • SVC, reactor or capacitor	Dynamic simulation	Transient stability, Voltage and frequency fluctuation range	None
	Steady state load flow	No voltage collapse, cascading outages, voltage step, emergency limits	None
	Steady state load flow	Normal limits	Tap-changing, Phase angle regulators, Generation dispatch, Switched shunts, Network switching
Overlapping Single Contingency and Generator Outage (N-G-1)			
• Generator + line • Generator + T/F	Dynamic simulation	Transient stability,	None

Disturbance	Analysis	Criteria	Allowable Remedial Actions
• Two generators • Generator + SVC, Reactor or Capacitor		Voltage and frequency fluctuation range	
	Steady state load flow	No voltage collapse, cascading outages, voltage step, emergency limits	None
	Steady state load flow	Normal limits	Tap-changing, Phase angle regulators, Generation dispatch, Switched shunts, Network switching
Trip- Maintenance (N-1-1)			
• Two lines • Line + transformer • Two transformers • Transformer + SVC, • Reactor or capacitor	Dynamic simulation	Transient stability, Voltage and frequency fluctuation range	None
	Steady state load flow	No voltage collapse, cascading outages	None
		Normal limits	Load shed 15 MW
	Steady state load flow	Normal limits	Tap-changing, Phase angle regulators, Generation dispatch, Switched shunts, Network switching

Disturbance	Analysis	Criteria	Allowable Remedial Actions
			Load shed 15 MW
Less Probable Contingencies			
Bus bar fault, bus bar coupler fault, breaker failure, protection failure, loss of double circuit line	Steady state load flow	No voltage collapse, cascading outages	None

4.7 South Africa

The Electricity Supply Commission (Eskom) is responsible for the Generation, transmission and distribution of electricity in South Africa. The transmission reliability standards adopted by Eskom are summarized below.

Transmission Contingencies

a. The transmission system is planned with sufficient capacity to ensure that supplies will not be interrupted in the event of a single outage "the N-1 criterion".

b. For transmission system operation, the responsibility for system security is identified in the South African Grid Code, which includes the obligation to operate the system such that in the event of the most severe double outage, there will be no instability, uncontrolled operation or cascading outages on the system.

c. For contingencies under various loading conditions, appropriate normally used generating plants are assumed in service to meet the load and provide spinning reserve. For the more probable N-1 contingency, the most unfavorable generating pattern will be assumed while for the less probable N-2 contingency an average pattern shall be used.

Power Plant Integration

When the integration of power plants is planned, the following criteria shall apply:

a. Power plants of less than 1000 MW

- With all connecting lines in service, it shall be possible to transmit the total output of the power plant to the system for any system load conditions. If the local area depends on the power plant for voltage support, the connection shall be made with a minimum of two lines.
- Transient stability shall be maintained following a successfully cleared SLG fault.
- If only single line is used, it shall have the capability of being switched to alternative bus bars and be able to go to bypass at each end of the line.

b. Power plants of more than 1000 MW

- With one connecting line out of service (N-1), it shall be possible to transmit the total output of the power plant to the system for any system load conditions.

- With the two most onerous line outages (N-2), it shall be possible to transmit 83% of the total output of the power plant to the system.

Stability Assessment

Transient stability shall be retained for the following conditions:

- A three-phase line or bus bar fault, cleared in normal protection time.
- A SLG fault cleared in "bus trip" times.
- A SLG fault, cleared in normal protection times, with any one line out of service.

4.8 Summary of International Experiences

Summary of the international standards discussed earlier is provided through the following data table:

Table 4.4: Summary for the International Standards

Country	Contingencies					
	Single Contingencies (N-1)		Multiple Contingencies		Extreme Contingencies	
	Contingency Elements	Acceptable Impact	Contin-gency Elements	Acceptable Impact	Contingenc y Elements	Acceptable Impact
NERC	• Generator • Trans-former • Trans-mission circuit • DC Pole	• System stable • Operation within emergency thermal and voltage limits • Operator Intervention allowed • Radial customers including load or generators are allowed to disconnect	• Bus section • Breaker failure • Bipolar (DC) line • Two circuits of multiple circuit tower line	• Accept-able impact same as for single contin-gencies • In addition load shedding and removal of certain gene-rators may be ne-cessary to maintain overall system reliability	• Tower line with three or more circuits • Transmiss ion lines in a common corridor • Substatio n • Power plant	• Loss of demand and gene-ration in a wide area • System may not be able to return to a new stable state • Extreme contin-gency events need to be evaluated for risks and conse-quences

Country	Contingencies					
	Single Contingencies (N-1)		Multiple Contingencies		Extreme Contingencies	
	Contingency Elements	Acceptable Impact	Contin-gency Elements	Acceptable Impact	Contingency Elements	Acceptable Impact
NORDIC Countries	• Generator • Transformer • Transmission • Circuit • DC pole • Bus section	In addition to load shedding and loss of generation needed to remove the fault, limited amount of load and generation may be switched off by automatic control	• Double circuit line • Stuck breaker • Two Generating units • Bipolar DC link	Controlled loss of load and generation is allowed for simul-taneous faults with common cause	Two or more simultaneous independent faults	Instability followed by extensive breakdown is expected

Country	Contingencies					
	Single Contingencies (N-1)		Multiple Contingencies		Extreme Contingencies	
	Contingency Elements	Acceptable Impact	Contin-gency Elements	Acceptable Impact	Contingency Elements	Acceptable Impact
Britain	**Demand Groups** • Trans-former • Trans-mission circuit • Cable • Reactor	• No loss of supply for group demand above 1500 MW • Limited loss of supply allowed for other group demands • Acceptable overloading and voltage conditions • System should remain stable		Acceptable impact same as for Demand Groups		
	Main Interconnected System: • Trans-former • Transmission circuit • Cable • Reactor	Acceptable impact same as for Demand Groups	• Double circuit line • Section of a bus bar			

Country	Contingencies			
	Single Contingencies (N-1)		Multiple Contingencies	
	Contingency Elements	Acceptable Impact	Contingency Elements	Acceptable Impact
Australia	• Transformer • Generator • Transmission circuit • Cable • Reactive plant	• No loss supply allowed • operator intervention allowed to secure operating state within 30 minutes • system should remain stable for normally cleared faults (other than three phase faults)	• Multiple generating units • Double circuit line • other contingencies involving three phase faults	• Load shedding allowed • System should remain stable for normally cleared faults (other than three phase faults)
Japan	• Transformer • Generator • Transmission circuit	• Blackouts not allowed unless their influence is small • Overloads allowed for limited period of time • Voltage stability should be maintained	Double circuit line	• Partial loss of supply allowed • Voltage stability should be maintained

<table>
<tr><th rowspan="3">Country</th><th colspan="4">Contingencies</th></tr>
<tr><th colspan="2">Single Contingencies (N-1)</th><th colspan="2">Multiple Contingencies</th></tr>
<tr><th>Contingency Elements</th><th>Acceptable Impact</th><th>Contingency Elements</th><th>Acceptable Impact</th></tr>
<tr><td>Ireland</td><td>• Transformer
• Generator
• Line
• SVC, reactor or capacitor</td><td>• No loss of load
• No voltage collapse or cascading outages
• Voltage and thermal emergency limits maintained
• Operator action allowed to bring system back to normal limits</td><td>• Bus bar fault
• Breaker failure
• Loss of double circuit line</td><td>Load shedding allowed but without voltage collapse or cascading outages</td></tr>
<tr><td rowspan="2">South Africa</td><td>a. N-1 contingencies for interconnected transmission system</td><td>• No supply interruption
• No operator Intervention
• No instability or uncontrolled operation or cascading</td><td>Double circuit outage</td><td>• Loss of supply allowed
• Operator intervention allowed to avoid instability, uncontrolled operation and cascading</td></tr>
<tr><td>b. N-1 contingencies for Power plant integration (over 1000 MW)</td><td>Total plant output should be transmitted</td><td>Double circuit outage</td><td>83 % of total plant output should be transmitted</td></tr>
</table>

5. Discussion on and Analysis of the Relevant Critical Aspects

5.1 Major Challenges Pertaining to Evacuation of Renewable Energy

One of the critical prerequisites for power evacuation from a renewable energy generation project is the connection to the transmission grid. Higher cost and delay may either modify the scale and scope of the project or prevent its development at all. Planning process for providing transmission facilities for renewable energy has gained paramount importance due to importance of timely connection of renewable energy, but also to reduce its cost. Need for transmission to be planned and developed ahead of time for renewable energy introduces an additional challenge. Traditional transmission planning practices can result in long delays in renewable energy projects.

Challenges with respect to evacuation of renewable energy are dominated by peculiar operation issues when scaling up renewable energy. These are considered the real-time operational issues that arise when integrating considerable amounts of variable renewable energy, such as wind and solar power. Generation from wind and solar power is inherently intermittent, and current technologies still offer less controllability than traditional power sources. Firstly, Wind or solar power output can change drastically, within minutes, and requires scheduling functions to respond quickly by pooling other generation sources and reserves in order to maintain the balance between supply and demand. As the amount of variable sources in the power system increases, the operational challenges multiply. In the context of this form of variability, experiences of countries like Denmark, Germany, Spain, and the United States in this regard over the last few years are very important and should be studied and taken benefit of. Secondly, variable renewable generation technologies do not always have the same control capabilities in voltage and frequency as other conventional, more controllable, power sources. The potential solutions include the use of improved forecasting in short-term dispatch operations, and better system wide controls and protections. Advances in voltage and frequency control of newer wind power plants are also playing an important role in managing these challenges better. These include pitch control in newer wind power generation technologies, which offer some degree of controllability of the power output. This study has not considered discussion on the way forward with respect to dispatch and control issues, however, it is important for SAARC Member States to take up these and define a strategy since it corresponds to smoothening the higher quantum of renewable energy evocation to the national grid.

A major technical concern is the reactive power regulation in large wind farms. Amount of the reactive power produced or absorbed by the wind farm and the grid changes because of the power changes at different wind speed (which is varying frequently). Reactive power produced in large scale wind farms cannot be ignored. As the wind power scale continues to expand, all the influence of wind power on energy quality shouldered by power grid is not economic or even affordable. Therefore, it is necessary to make appropriate reactive power compensation within wind farms to be constructed. The Grid Code of India states that the State Load Dispatch Centers shall take into account Wind Energy forecasting to meet the active and reactive power requirement. Other Grid Codes do not specify any provisions for considering wind forecast in preparing schedules.

As such, Indian Planning Criteria includes considerations for tackling this issue in concrete terms that pertains to Shunt Capacitors, Shunt Reactors, Static VAR Compensation, additional criteria for Sub-station Planning, wind and solar projects, nuclear power stations and HVDC transmission systems. As already highlighted, this aspect is exclusively important for evacuation of large amount of renewable energy.

5.2 Regional Connectivity – SAARC Energy Ring (Electricity)

An electrically inter-connected South Asia would require adjustment of inconsistencies among measurements, methods, procedures, schedules, specifications, and systems to make them uniform or mutually compatible. A lot depend upon the type of interconnection. In case of a synchronous interconnection, voltage, basic insulation strength, nominal frequency and protection scheme must match on the either end. In case of asynchronous interconnection, the fault occurring on one side is not passed on to the other side, so both the sides have to worry less about each other on these aspects. Nevertheless, the tripping of HVDC terminal would itself constitute a disturbance in terms of loss of load or loss of supply.

5.2.1 Master Plan for the SAARC Grid

Pursuant to the Article 7 of the SAARC Framework Agreement for Energy Cooperation (Electricity) as regard to planning of cross border interconnections, a consolidated Regional Plan is vital and required to be prepared for each of the cross border links between the Member States. The Regional Plan can be for bilateral transactions or multilateral transactions but will eventually cover the entire SAARC region. It is intended that the Regional Plan shall cover a horizon of the next 10 to 20 years. A few yet important aspects with respect to setting up SAARC Energy Ring are discussed as follows:

5.2.2 Planning of Cross Border Interconnection as Regulatory Obligation

Grid Code of Bhutan exclusively specifies that planning of the transmission system for export of power from the generating stations to the neighboring countries shall be discussed and reviewed with the concerned agencies of the neighboring countries. Regulatory instruments of other SAARC Member States do not include any provisions for planning cross-border interconnection. Such provision in the list of regulatory obligations for all the SAARC Member States is vital with respect to implementation of SAARC Energy Ring (Electricity).

5.2.3 Development of Planning Scenarios

In order to plan the SAARC Energy Ring (Electricity) with respect to bilateral and multilateral power interconnections, various planning scenarios are required to be defined to represent future developments. Such scenarios are means to approach the potential uncertainties and the interaction between these uncertainties. Anticipating that implementation of the transmission infrastructure plan to take around 10 years, it is imperative develop scenarios covering the timeframe beyond ten years. A study by USAID SARI/EI (Harmonization of Grid Codes Operating Procedures and Standards) suggested the following factors for developing the scenarios:

Table 5.1: Suggested Factors for Developing Scenarios

Characteristic	Factors
Time Horizon	Mid Term (5 – 10 years)

Characteristic	Factors
	Long Term (15 – 20 years)
	Very Long Term (30 years)
Technical Parameters	Plant Efficiency
	Availability
	Reserves
	Share of non-dispatchable generation
	Ramping and start-up costs
Economical Parameters	Economic growth
	Fuel cost
Generation Scenarios for different generation types	Capacity
	Efficiency
	Flexibility
	Location
	Renewable production
	Wind/solar profiles or cold/heat spell
Demand Scenarios	Economic Growth
	Evaluation of Demand per sector
	Load Management
	Climate (e.g. Wind, temperature,
	Season (e.g. Winter, summer)
	Population
Exchange Pattern	Inter region and inter country fixed flows

5.2.4 Importance of Reactive Power in the Perspective of Regional Connectivity

Reactive power plays a critical role in the operation of power transmission system; consequently, forecast of reactive power demand on a system-wide basis is as important as that of active power. However, currently, except for Member State India, forecast of reactive power demand is not being computed. Further, reactive power flow over the HVAC transmission system needs to be minimized.

5.3 Fuel Diversity

The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance. https://www.iea.org/topics/energysecurity/

Energy security is mainly threatened by either the physical supply of energy or its price. Best practices with respect to managing energy security include diversity of fuel supplies, spare capacity in generation and transmission infrastructure.

Diversity of fuel with priority assigned to sustainable, indigenous resources is considered as vital for energy security. Taking example of Pakistan's energy mix, an unprecedented reliance on thermal power based on imported fossil fuel is observed.

Lately, induction of imported Liquefied Natural Gas (LNG), in large chunks has further threatened the energy security. However, the share of hydropower despite of significant increase in the last two decades (replaced by imported fossil fuel) is still encouraging. With this Pakistan has also induced significant amount of power from imported coal which is being followed by upcoming coal power from local resources, expected to be commissioned by end of the year 2018.

Though Planning Criteria does not include regulation of the generation mix, transmission utilities, under the regulated regimes, are usually obligated to develop indicative generation capacity expansion plans. It therefore becomes the obligation of transmission utilities to thoroughly discuss and come up with an indicative generation plan which is based on optimized generation mix comprising sustainable, indigenous resources, as much as possible.

5.4 Frequency and methodology of Updating/Reviewing Planning Criteria

Keeping in view the criticality of planning criteria in development, operation and maintenance of the power grid, it is required to consider it as a dynamic element which should be reviewed and updated with changes in priorities usually reflected in the power policy as well as the major effects of such policy and corresponding power sector plans. Learning from the international practices remains the key since not much is being invested in South Asia for research activities. Defining an exclusive System Operating Procedure (SoP) in the Grid Code could be one idea to reduce the delay in formal approvals as a special committee could be made responsible to review and suggest changes in the planning criteria, may be once in a two years time.

6. Recommendations

Based on the learning through this brief, in-house research intervention, a few changes are suggested in this section to the existing planning criteria of the SAARC Member States pertaining to important aspects such as renewable energy, fuel diversity, ever increasing load quantum and regional interconnectivity leading to SAARC Energy Ring.

1. Transmission planning criteria should specify more stringent security and reliability limits at planning stage than the current operational security and reliability limits. A planning margin would thus be specified for voltage limits, thermal loading limits of lines and transformers, reactive capabilities of generators, fault levels etc. (SAARC Member States who specify operational security limits as planning criteria, would be following the example of Member State India.)

2. In order to cope with the issues coming up with the higher quantum of wind energy in the national energy mix, short term/operational forecast of Wind Energy is required to be assessed to meet the active and reactive power requirement. (*With this, Member States will be following Member State India.)*

3. Exclusively for critical elements, Indian Grid Code requires ‘N-1-1’ criteria. Keeping in view the huge investments required by other Member States to comply with this regulation, it is suggested to include this regulatory requirement in the Planning Criteria of each of the Member States, and Member States be facilitated to manage compliance by spreading the investment over a reasonable timeframe.

4. Reactive power plays a critical role in EHV transmission system management and hence forecast of reactive power demand on a system-wide basis is as important as active power forecast. This forecast would obviously require adequate data on the reactive power demands as well as the projected plans for reactive power compensation. Further, in the AC interconnection (synchronous), the reactive power flow shall be minimized and shall be operated within 0.97 lead/lag power factor at connection point and within permissible voltage variation.

5. With the aim to complement the national energy mix with the optimized share of indigenous resources i.e. renewable energy, system operator is required to be mandated to consider Wind and Solar plants as ‘MUST RUN’ generation plants for scheduling purposes and should make all efforts to evacuate the available Solar and Wind power. With the assignment of this mandate, the SAARC Member States would be following Member State India.

6. All Grid Codes except for India require adequate operating reserves (Spinning/Contingency/ Stand-by) to be made available for use during contingency conditions and large demand variation conditions. However, Indian Grid Code has adopted a different approach i.e. it requires that all thermal generating units of 200 MW and above and all Hydro units of 10 MW and above operating at or up to 100% of their Maximum Continuous Rating shall be capable of instantaneously picking up to 105% and 110% respectively. Nonetheless, compliance of such regulations relating to generation sufficiency is highly important for ensuring system adequacy.

7. All SAARC Member States are sensitized towards ensuring dynamic stability, which is evident from the relevant provisions of the Grid Codes. However, Bangladesh, India and

Pakistan specify that system shall survive a permanent 3-phase to ground fault on EHV lines with a fault clearance time of 100 ms. Additionally, Indian Grid Code specifies many other disturbances in detail for assessing system stability. Aiming at improved system stability especially in view of a number of upcoming bilateral and multilateral cross border interconnections, all Member States should consider including such regulations in their respective planning criteria.

8. For preparation of an integrated Regional Plan – an important pre-requisite for materializing SAARC Energy Ring (Electricity), following may be considered as planning guidelines:
    a. Scope of the plan would be macro level transmission planning for cross border interconnection/trading considering 400 kV and above network in connected Member States for next 10 or 20 years.
    b. This shall include existing bilateral and future bilateral as well as multilateral export and import agreements between the Member States.
    c. The Regional Plan (covering both generation and transmission expansion) also shall include feasibility studies for future years with various possible scenarios.
9. In the particular context of materializing of SAARC Energy Ring i.e. upcoming cross border interconnections, each of the planned cross border link should satisfy N-1 contingency for HVDC links and N-1-1 for AC interconnection. Stringent compliance in case of HVAC interconnection is justified since HVDC is inherently safer.
10. Following the example of Member State Bhutan, Grid Codes of all Member States should specify that planning of the transmission system for export of power from the generating stations to neighboring countries shall be discussed and reviewed with the concerned entities of the neighboring countries. In the perspective of regional interconnection or more specifically of implementation of SAARC Energy Ring (Electricity) such regulatory requirements need to be added for compliance.

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