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Comparative Analysis of Post-Interconnectivity Reinforcement of the Isolated Gwadar/Mekran Region with the National Grid for Optimal and Reliable Performance

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ABSTRACT

The Gwadar / Mekran area in Pakistan currently faces significant challenges in meeting its electricity demands, relying on power imports from Iran and decentralized generation sources. To address this issue and bolster economic growth, a project proposal for interconnecting the region with the National Grid System of Pakistan was initiated. The proposed interconnection scheme includes the construction of double and single-circuit 132kV transmission lines, extensions of grid stations, installation of shunt capacitors, and Static Var Compensators (SVCs).The project aims to integrate multiple key power sources, including the Gwadar 300 MW Coal power project, through the proposed transmission lines of various lengths. Additionally, the plan includes stringing second circuits with Cairo Conductors to improve grid efficiency and reliability. A new 132 kV Grid Station at Nag and extensions to existing grid stations are also part of the scheme, along with the installation of shunt capacitors and SVCs at strategic locations to enhance power quality. The estimated cost of the project is Rs. 60,070.21 million, with an economic rate of return of 18.48% and a financial rate of return of 13.40%. The successful implementation of this interconnection project is expected to provide reliable electricity supply, support industrial and commercial growth, and uplift living standards in the Gwadar/Makran area. The research objectives encompass a comprehensive evaluation of the proposed interconnection scheme, technical feasibility, and reliability, along with an economic analysis of the estimated cost and financial returns. Additionally, the study will assess the socio-economic benefits, including improved electricity supply, enhanced industrial and commercial activities, and job creation in the region. By exploring the impact on voltage profile and system efficiency, the research will ensure a stable and reliable power supply. The expected outcomes are to provide valuable insights for informed decision-making by policymakers and stakeholders, ultimately leading to sustainable development, economic growth, and improved living standards in the Gwadar/Makran area and the nation as a whole.

INDEX TERMS interconnection, Grid , power supply, reliability , reinforcement

I. INTRODUCTION

The interconnection of the Isolated Mekran/Gwadar area with the National Grid System of Pakistan is a significant step towards addressing the region's energy challenges and enhancing its power supply reliability reported by QESCO supply company.Currently, the Mekran region, including Gwadar city, heavily relies on power supply from the Islamic Republic of Iran. Specifically, 100MW of power is imported from Jackigor (Iran) to Mand (Pakistan), and another 100MW is imported from Polan (Iran) to Gabd/Jiwani (Pakistan). However, with the ongoing interconnection project, the dependence on power imports from Iran will gradually reduce.By the end of December 2023, QESCO anticipates that it will be able to obtain 280MW of power from all sources combined. This includes the 100MW from Jackigor (Iran), 100MW from Polan (Iran), and an additional 80MW from the National grid system of Pakistan. The interconnection with the National Grid System of Pakistan will enhance energy

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access and promote economic growth in the region.QESCO (Quetta Electric Supply Company) was advised for interlinking of Gwadar Area with National Grid Systems of Pakistan and Iran along with evacuation of Power from newly proposed 300 MW Power Project of Gwadar. Therefore, transmission /grid system study for Interlinking of Gwadar / Makran Area with national grid is required.This research proposal seeks to conduct an in-depth analysis of the proposed interconnection project, exploring its technical feasibility, economic viability, and potential socio-economic impacts. By scrutinizing the technical aspects of the transmission lines, grid station extensions, and supportive infrastructure, as well as conducting a cost-benefit analysis and impact assessment, the study aims to provide valuable insights for informed decision-making by policymakers and stakeholders .

II. CONTRIBUTION / SIGNIFICANCE OF THE STUDY

In terms of its academic contribution, the research seeks to thoroughly examine the technical feasibility and reliability of the proposed interconnection scheme. Through an assessment of various power sources and grid efficiency, this study will offer valuable technical insights and innovative solutions to enhance electricity supply systems and grid management. From a policy standpoint, this *C.* research will inform decision-makers and policymakers about the potential socio-economic benefits of the interconnection project. By evaluating its economic viability and potential returns on investment, the study can guide energy policies and strategies that support sustainable development and energy security in Pakistan. Significantly, the study's outcomes will be of particular importance to the industrial sector in the Gwadar/ Makran area. With improved *D.* and dependable electricity supply, industries can anticipate increased productivity, reduced production costs, and heightened competitiveness. Furthermore, the interconnection project can attract new investments, stimulating industrial growth and fostering a favorable business environment.

III. LITERATURE REVIEW

A. Interconnection Projects and Grid Integration:

E. Interconnection projects have been widely studied as a means to enhance electricity supply, grid stability, and regional energy cooperation. According to Kim et al., interconnecting regional grids can facilitate efficient power exchange and improve the reliability of electricity supply [7]. Studies by Bayatpour et al and Sun et al emphasize the importance of interconnection projects in promoting renewable energy integration and reducing greenhouse gas emissions [8] [9]. However, a gap in the literature lies in the context-specific evaluation of interconnection schemes and their potential socio-economic benefits, particularly in the Gwadar/Makran area of Pakistan.

B. Socio-Economic Impacts of Energy Projects:

The socio-economic impacts of energy projects have been a subject of interest in the literature. Research by Shafiei and Salim and Omri and Daly explores the relationships between energy consumption, economic growth, and environmental sustainability [10] [11]. Findings indicate that improved energy supply can stimulate economic activities and create employment opportunities. However, the specific socio-economic impacts of interconnection projects in remote and underserved regions like Gwadar/Makran are yet to be adequately examined.

Sustainable Development in Remote Region

Sustainable development in remote regions, particularly in terms of energy access and poverty alleviation, has been studied by Zerriffi and Koirala et al. [12] [13]. The literature highlights the importance of affordable and reliable energy supply to uplift living standards and promote inclusive growth. Nevertheless, research on the potential role of interconnection projects in achieving sustainable development objectives in such areas is limited.

Energy Projects in Pakistan:

Pakistan's energy landscape and policies have been studied by researchers like Ahmad et al. and Farooq et al. [16] [17]. The literature highlights the importance of energy diversification and infrastructure development for sustainable economic growth. However, there is limited research specifically focused on the interconnection of Gwadar/Makran area with the National Grid System of Pakistan and its potential implications for the region's economic development.

Research Gap and Proposed Contribution:

While existing literature highlights the significance of interconnection projects and energy access for sustainable development, a specific focus on the Gwadar/Makran area and its integration with the National Grid of Pakistan is lacking. The proposed research aims to bridge this gap by providing a comprehensive analysis of the technical feasibility, economic viability, and socio-economic impacts of the interconnection project in this particular context. By exploring the potential benefits and challenges of the project, the research will contribute novel insights and specific recommendations for policymakers, energy

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authorities, and industry stakeholders. Additionally, the study will extend the existing literature by evaluating the role of interconnection in promoting clean energy integration, improving grid resilience, and fostering inclusive economic growth in remote and underserved regions of Pakistan.

F. Theoretical Studies:

The research will begin with an extensive review of theoretical studies related to interconnection projects, renewable energy integration, and socio-economic impacts. Relevant literature on grid integration, energy access, and sustainable development in remote regions will be critically analyzed to establish a theoretical framework for the study. Theoretical studies will guide the selection of variables, indicators, and methodologies for data collection and analysis.

The research will be primarily based on comprehensive system studies conducted by independent consultants, M/s Power Planners International Lahore. The research team will collaborate with the consultants to access the required data and technical documentation related to the proposed interconnection project. The study will not involve physical experimentation but will focus on analyzing technical and economic feasibility reports and environmental impact assessments.

G. Interconnection Results in Lowering Energy Prices

South Africa provides the largest percentage of electricity on continental Africa. There exist sufficient amount of both gas and hydro at affordable prices in South Africa. To lower the electricity prices at continental Africa, interconnection of south Africa with continental Africa is required.

P.Naidoo and L.Musaba suggested the use of power pool model and use of Inter pool energy transfer using EHVDC or UHVAC for continental interconnection are key elements that can support constraint of sustained worlds lowest cost electricity prices. The approach is unique but practical [19]4

H. Stability Issue in Interconnection

Worldwide interconnection trend is to achieve economical benefits. The interconnection may be AC, CC or combination of both. The evaluation of best solution for large power system requires detail system model for stability analysis.

Bernd M. Bucholz et al. concluded that interconnection will results in reliability problems. For each interconnection detailed analysis needs be performed. Stability problem resulted from interconnection can be solved by use of FACTS and HVDC [20].

I.Ferranti Effect and Voltage Control

The voltage control in transmission system at both no loads, lightly load and loaded condition is possible with compensation devices like FACTS devices.

Venu Yalagadda et al. worked on the analysis and mitigation of Ferranti effect and voltage control of transmission lines with Fuzzy logic control and found that Fuzzy based close loop control of SVC is quite effective in controlling the terminal voltage under no load, light load and heavy load conditions [21].

IV. RESEARCH AIM AND OBJECTIVES

The primary objective of this study is to assess the viability of connecting the Gwadar/Makran region to Pakistan's National Grid System. This endeavor seeks to determine the feasibility of this connection while also examining its potential for delivering socio-economic advantages. The ultimate aim is to establish a dependable and consistent electricity supply, thereby supportin sustainable economic development and raising living standards in the area.

1. Evaluate the technical feasibility and dependability of the proposed interconnection plan, which encompasses both double and single-circuit 132kV transmission lines and extensions to new or proposed grid stations.
2. Undertake a comprehensive economic analysis to assess the projected costs, foreign exchange components, and financial rate of return associated with the interconnection project.
3. Examine the potential socio-economic ramifications, including increased industrial and commercial activities, job creation, and enhanced living conditions, stemming from the provision of reliable electricity.

Scrutinize the environmental impacts of the project, with a particular focus on promoting clean energy sources and aligning with sustainability objectives.

4 Confirm the credibility of the proposed research through thorough system studies ensuring both technical precision and impartial evaluation.

III. DATA AND METHODOLOGY

The methodology followed to accomplish the objectives of this project is summarized in the following steps;

Latest available Generation Expansion Plan i-e IGCEP (Indicative Generation Capacity Expansion Plan) provided by NTDC.

Load forecast for each grid station was developed as summarized in the following steps (more details are presented in the Load Forecast Report):

a) Data used is the 11 kV feeder-wise and tariff category-wise sales. It also includes the maximum demand of medium and large industries for the base year.

B These sales are converted into peak demand using the load factors and diversity factors.

C Growth rate on each category is applied and spot load are added.

This way the peak demand of the next year at each grid station is forecasted. The summation of these peak values is the non-diversified peak load (i.e 2538MW by Year-2026. The peak demand segregated as QESCO common area and Mekran area i.e. 1463MW and 148MW respectively. The co-incidence factor for QESCO common area is taken 61% while for Mekran area it is 95% to incorporate the future growth

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under CPEC project as no realistic data was provided by GDA and GPA. The later (diversified peak) is the value to be used in transmission planning (132 kV network).

The load data was obtained from the *"PMS Load Forecast Report of QESCO for the year 2021-22"*

iii. he load flow case representing the current system (2022-23) has been modified to include the 11 kV network. Each 132 kV or 66 kV bus was expanded to model the 132/11 kV or 66/11 kV transformers. Loads have then been placed at the 11 kV side along with the shunt capacitor banks, if any. The actual measured values of bus voltages, power factors, active and reactive power energy), and loadings on lines and transformers were matched with the simulated solutions to determine the actual power factors of loads at different substations. These calibrated power factors were used for modeling of loads (MW/MVAR) while developing the simulation cases. **1.1**

iv. Loads were updated based on the load forecast values for Year-2026 including the addition of the new grid stations as appropriate and the established load power factor .All the sub-projects planned under ADB and PSDP or 7th STG would be a part of the interconnected network in the Year-2025 base case.

v. The generation schedule on the transmission level (220 kV and higher) would be increased (if necessary) to match the load level. i.

vi. After that the 132kV system analysed under both normal (N-0) and contingency (N-1) conditions. As a result of this analysis, system reinforcements were added as necessary. Then the Year-2026 case with reinforcements was re-analysed under (N-0) and (N-1) conditions. ii.

vii. The Power Factor of the load is taken as 0.85 while that for the Line/Bus Bar is 0.95.

iii.

viii. ***Normal operating conditions (N-0)***: The Secondary Transmission System (66-132 kV) infrastructure is entirely available (no equipment has been considered out of service).

ix. ***Contingency operating conditions (N-1)***: one of the Secondary Transmission System equipment (line or transformer) is out of service. In this study, only outage of transmission lines was considered.

x. For each of these operating conditions, the following criteria were applied to the analyses;

System Voltage Criteria:

The voltage range acceptable for operating the system based on factors such as equipment limitations under normal and contingency conditions is as follows:

Table ***Error! No text of specified style in document.****-1: System Voltage Criteria*

Condition	
System Conditions (Normal)	
Contingency Conditions	

From an operational stand point, it is important to note that healthy systems usually target a voltage close to 1.0 pu at 132 kV(or 66kV) voltage levels.

Power Factor Criteria:

Table ***Error! No text of specified style in document.****-2: Power Factor Criteria*

Condition
Load Power Factor
Maintenance of Power Factor at Bus Bar

All the future Proposed/New Grid Stations planned under ADB/PSDP or in 7th STG would be a part of the interconnected network in the Year-2026 case and it is added accordingly.

The 132kV system is then analyzed under both normal (N-0) and contingency (N-1) conditions. As a result of this analysis, system reinforcement's i-e New Grids, Transmission Lines, Capacitors, SVC's etc will be added as per requirement.

State of art software Power System Simulation for Engineering (PSS/E) of Siemens will be used.

1.1 Equipment Thermal Loading Criteria:

The Secondary Transmission System shall be planned to allow all transmission lines and equipment to operate within the following limits for the following defined conditions:

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*Table **Error! No text of specified style in document.**-3: Equipment Thermal Loading Criteria*

Condition	T
Normal System Conditions	D
System Design Contingencies of Long Duration(i.e. an outage involving the failure of a transformer)	D
System Design Contingencies of Short Duration(i.e. not involving a transformer)	D ra

6	132 kV Gwadar	T-1
		T-2
7	132 kV Pasni	T-1
8	132kV Gwadar Ind Estate	T-1
9	132 kV Ormara	T-1
10	132 kV Jiwani	T-1
11	132 kV Deep Seaport	T-1

1.2 Gwadar/Mekran Area Existing Network (Grid Station, Power Transformers, 11kV and 132kV Capacitors, Reactors and Transmission Lines)

Gwadar/Mekran Area is currently feeding from two numbers of sources from Iran i-e 200MW from Jackigor (Iran) to Mand (Pakistan) and 200MW for Polan (Iran)-Jiwani (Pakistan).
Detail of the existing Grid Stations, Capacitors and Transmission Lines at Gwadar/Mekran is given below:

1.2.1 Detail of Existing Grid Stations and Power Transformers

*Table **Error! No text of specified style in document.**-4: Existing Grid Stations and Power Transformers*

Data of Existing Grid Stations & P at Gwadar/Mekran		
Sr No.	Name of Grid Station	Power T/F's Designation
1	132 kV Turbat	T-1
		T-2
		T-3
2	132 kV Tump	T-1
3	132 kV Mand	T-1
4	132 kV Panjgur	T-1
		T-2
5	132 kV Hoshab	T-1

1.2 Detail of Existing 11kV Capacitor Banks

*Table **Error! No text of specified style in document.**-5: Existing 11kV Capacitor Banks*

Data of Existing 11kV Capacitor Bank			
Sr No.	Name of Grid Station	MVA Rating/Capacity of Capacitor Bank already installed	
	132 KV Turbat		4.8
			7.2
			4.8
2	132 KV Tump		4.8
3	132 KV Mand		4.8
4	132 KV Panjgur		4.8
			7.2
5	132 KV Hoshab		3.6
6	132 KV Gawadar		7.2
			2.4
7	132 KV Pasni		4.8
8	Gawader Estate		4.8
9	132 KV Ormara		4.8

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10	**132 KV Jiwani**	4.8
11	**132 KV Deep Seaport**	7.2

1.2.3 Detail of Existing 132kV Capacitors

In the existing network only one 132kV Capacitor is installed at 132kV Grid Station Turbat in Gwadar/Mekran area. Detail is given below

*Table **Error! No text of specified style in document.**-6: Existing 132kV Capacitors*

Sr. No	Name of Grid Station	Total Capacity (MVAR)
01	132kV Turbat	24

1.2.4 Detail of Existing Surge Reactor

In the existing network one Surge Reactor is installed at 132kV Grid Station Panjgur in Gwadar/Mekran area. Detail is given below

*Table **Error! No text of specified style in document.**-7: Existing Surge Reactors*

Sr. No	Name of Grid Station	Total Capacity (MVAR)
01	132kV Panjgur	5

1.2.5 Detail of Existing Transmission Lines at Gwadar/Mekran Area

*Table **Error! No text of specified style in document.**-8: Existing Transmission Lines*

Existing Transmission Lines at Gwadar/Mekran Area

Sr. No.	***Name of G/Station***	***Volt KV***	***Controlling Breaker This End***	***Controlling Breaker Other End***	***Length of T/LINE KM***	***Conductor Type***	***Capacity MVA***
1	**132 KV Jakigor (Iran)**	132kV	Iran	Mand	28	RAIL	202
2	**132 KV Mand**	132kV	Mand	Tump	45	Cairo	117

3	**132 KV Tump**	132kV	Tump	Turba
4	**132 KV Turbat**	132kV	Turbat	Hosha
5	**132 KV Hoshab**	132kV	Hoshab	Panjgu
6	**132 KV Turbat**	132kV	Turbat	Pasn
7	**132 KV Pasni**	132kV	Pasni	Gawad
8	**132 KV Pasni**	132kV	Pasni	Orma
9	**133 KV Iran(Polan)**	132kV	Iran	Jiwar
10	**132 KV Jiwani**	132kV	Jiwani	Gwad
11	**132 KV Gwadar Ind**	132kV	Gwadar Ind	Pasn
12	**132 KV Gwadar Ind**	132kV	Gwadar Ind	Dee Seapo
13	**132 KV Gwadar**	132kV	Gwadar	Dee Seapo

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1.2.6 Geographical Map (Existing)

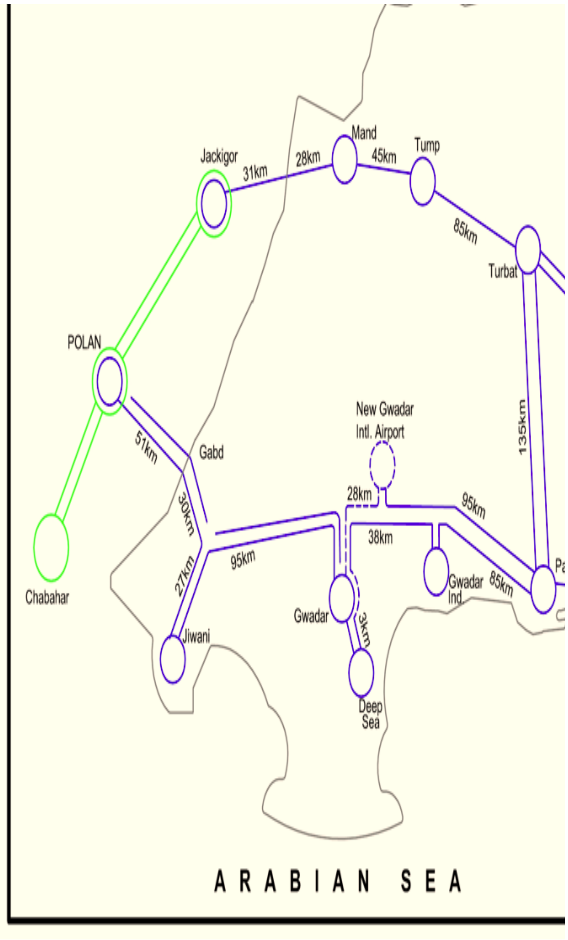

*Figure **Error! No text of specified style in document.**-1:Geographical Map (Existing)*

1.2.7 PSS/E Network of Gwadar/Mekran Area (Existing)

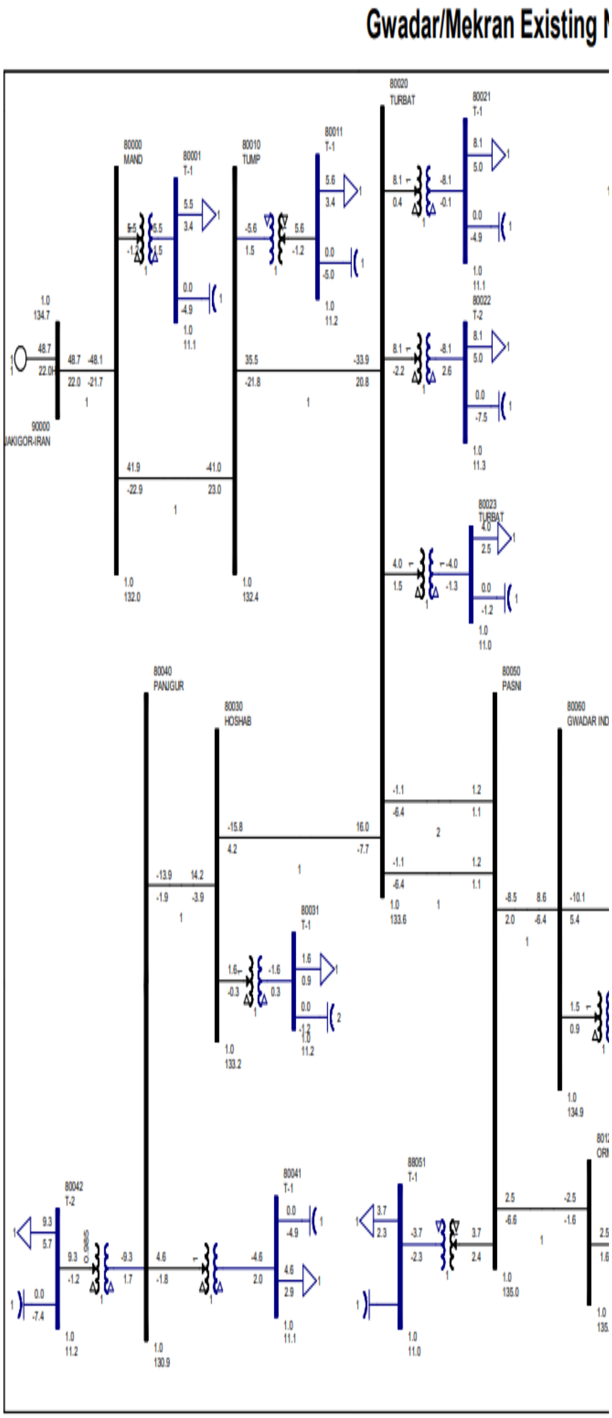

*Figure **Error! No text of specified style in document.**-2: PSS/E Network (Existing)*

IV. CONCLUSION, RECOMMENDATIONS AND WAY FORWARD

A. *RESULTS CONCLUSION*

- The ongoing long-term transmission expansion plan for Gwadar/Makran is in progress, involving periodic studies to connect the isolated Gwadar/Makran Area to the National Grid effectively. This study aims to link the Gwadar/Makran area with the national grid through a 132kV network and propose additional reinforcements for providing reliable, optimal, and cost-effective power to the region.
- Without reinforcements, the Khuzdar 220/132kV Grid Station lacks sufficient capacity to meet the demand of the entire Gwadar/Makran area, as the interlinking is accomplished through the distant 220/132kV Khuzdar. It's noteworthy that the lengthy lines and low load in the area may lead to the Ferranti effect, where voltage at the receiving end increases. To address these challenges, it is recommended to source power from three locations: the National Grid, Jackigor-Mand, and Polan-Jiwani (Gabd).
- Initial analyses without reinforcement revealed issues such as insufficient capacity and high voltages, prompting a subsequent analysis with reinforcements, including transmission lines, grid stations, power transformers, and capacitors proposed for the future. These analyses considered the 2026 demand for Gwadar area grids the PSS/E case for 2026, and planned projects in the Gwadar [2] area until 2026.

A. RECOMMENDATIONS

The system operator needs to make sure that the pre-energization voltages at the substation sshould be kept in permissible limit i.e., below 1.05 per unit as identified in the study for each step.

For the control of voltages, following measures are suggested:

Voltage control through adjusting tap positions of 220/132kV auto transformers at 220kV/132kV Khuzdar grid station.

Line openings in the vicinity of the network to avoid excessive charging and over-voltages.

Line reactor at Panjgur grid station (5MVAR) could be utilized as an option to absorb reactive power and reduce voltages.

A. FUTURE RESEARCH

•The analysis conducted encompasses various scenarios, including both existing and future conditions, with the goal of ensuring reliability and optimal operation. In the current state, it is suggested to operate the system using three different sources to address a significant increase in voltage. In this configuration, a ring arrangement involving a Coal Power Plant and an Iran supply is employed. Notably, in this scenario, no additional reinforcement is necessary, and surplus power is directed towards Iran.

•However, a key challenge arises in situations where there is no supply available from Iran and the Coal Power Plant. To maintain reliability and optimize operation under these circumstances, the system requires additional reinforcement. This is achieved by introducing Static Var Compensators (SVCs) at different locations. These SVCs play a crucial role in regulating the voltage levels and ensuring stability when the primary sources are unavailable.

•In summary, the proposed approach involves a flexible and adaptive system configuration that can seamlessly adapt to different operational scenarios, ensuring reliability and optimal performance through the strategic deployment of various components based on the availability of power sources.

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