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Research article

Mitigation of power evacuation constraints associated with transmission system of Kawai-Kalisindh-Chhabra thermal power complex in Rajasthan, India

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Abstract: Transmission system of the Rajasthan state, India is used to transfer power from the centralized generating stations to load centers. There is a thermal complex in the Kota region which includes four thermal power stations (TPS). These are Kawai Super Critical TPS (SCTPS), Chhabra TPS, Chhabra SCTPS, and Kalisindh TPS. Existing transmission system is not sufficient to evacuate power from this thermal complex during the contingency conditions. Hence, restructuring of the existing power network is required to mitigate the power evacuation constraints from this thermal complex. This research presents an optimized design for the restructuring of the transmission network associated with this thermal complex to mitigate power evacuation constraints. This is achieved by analysing the various possible options of the creation of various 400/220 kV GSS or 220/132 kV GSS in the region. Research also considered replacement of the existing ICTs at the thermal power stations by ICTs of higher ratings. The strength of the proposed restructured power system network is tested during various contingency conditions so that the power system network always takes care of power evacuation from the thermal complex and avoids the requirement of backing down the generation. Modified network is tested using the load flow study as well as a short circuit study. Results of these studies established that creation of 400/220 kV GSS at Sangod will be technically most feasible, effective and sufficient to mitigate the power evacuation constraints

associated with the thermal complex. The study is performed using the MiPower software.

Keywords: power evacuation constraint; load flow study; Short circuit study; Thermal power plant; transmission system; utility grid

1. Introduction

Transmission system is a complex network operated at different voltage levels. It is used to transfer bulk amount of power from centralized generating stations to load centres. Transmission network in the Rajasthan state of India is constructed, operated and maintained by the state transmission utility (STU). The Rajasthan Raja Vidhyut Prasaran Nigam Ltd. (RVPN) performs the activities of the STU in the Rajasthan. RVPN maintains transmission network rated at voltage levels of 132 kV, 220 kV, 400 kV and 765 kV. Restructuring of existing transmission network helps to solve the problems of constraints in evacuation of power from the generating stations. Restructuring also helps to meet increased demand. Different methods are found in literatures, which are focussed on restructuring of power system network. A broad study to investigate impacts of restructuring of the power procurement structure on the performance of the power plants (steam, gas and combined cycle thermal power plants) in the Iranian power system is presented in [1]. Authors introduced a slack-based model for the power system restructuring to calculate efficiency of technological changes for the duration of 8-years (2003–2010) in post restructuring period. Bhatt et al. [2], presented an automatic generation control (AGC) algorithm for the control of generation in the restructured power system. In [3], authors proposed a method of load frequency control (LFC) for the power system network to evacuate power from an integrated two-area network, which has multiple-unit thermal power plants (TPP). In this study, impacts of apparatus having wide range of capacity and high rate of power consumption in restructured power network is investigated. In [4], authors developed a model, based on the game theory, for assessing impacts of carbon dioxide cap and trade programs in electricity markets under the restructured power system network. The proposed approach is applied on a sample power system network designed by using the data of electricity market of the northern Illinois region of the United States. A method is designed by the hybrid neural network (NN) and Fuzzy logic (FL), to solve the issues of automatic generation control (AGC) in the restructured network of power [5]. The proposed approach has the advantage of high insensitivity to heavy changes in the load, disturbances associated with the plant parameter discrepancy and nonlinearities of the system. In [6], authors presented a method supported by the Stockwell transform and fuzzy clustering for the power quality assessment and event detection in distribution network with wind energy penetration. A detailed analysis of low voltage ride through (LVRT) techniques used to protect the grid integrated wind generators from faulty and islanding events is reported in [7]. A method for the assessment of power quality with wind energy penetration in weak AC grids is presented in [8].

Restructuring of power system network has been carried out in the different countries of the world due to various reasons. The Romanian government has taken a step, in 2010, towards restructuring of the state utilities network and assets of state owned power generation system. This had been achieved by creating two power companies at national level. These companies help all the power generation assets, which are being owned by the state governments or by these two power companies' and related to coal-mining. This restructuring is also speeded up by the three distribution companies owned by the state at regional levels. The Ministry of Economy, Trade and Business Environment has taken a decision in the Romania for the restructuring of the majority assets of power generation in the Romania [9]. In [10], authors analysed the welfare related complicacies associated with the implications of reforms of the state power-sector utility in the West Bengal state of India, during a condition where both the public-sector and private sector utilities are available. A period of fifteen-years has been considered for the review, which includes the pre-restructuring and post-restructuring periods. Analysis of the panel data related to the four customer categories gives the negative impact, associated with the disintegration on the welfare related activities. This is due to the increased cost of the transmission and enhanced rates of the tariff, which results in decreased number of power consumer and energy producers. In [11], authors examined the process adopted for the implementation of various government schemes in a village, situated in the northern China. Authors focussed mainly on the interactions between consumers and their impacts on restructuring process in the rural areas. In [12], authors illustrates that electrical power industry has undergone restructuring in the United States of America (USA). This began in 1990 and aimed to improve competitiveness of electricity market for the effective allocation of resources at reduced cost. The restructuring is implemented in the State of Delaware first time. The customers had the possibilities to purchase power from various electricity generators in the restructured market. This study presented a comparative study between the electricity prices for the restructured power network. It is observed that higher electricity rates exist in the restructured market compared to the non-restructured states. This forces the utilities to understand the welfare and satisfaction of customers in the post restructuring period. Yousefi *et al*. [13], presented a detailed report on restructuring of the electricity market in Iran. Initial steps for the restructuring of the electricity industry in Iran were started in 1990. This led to launch the wholesale electricity market in November 2003. Achievement of long-term security of electrical supply, settlement of the electricity prices and attraction of the private investors are important key goals of electricity industry restructuring. Third development plan was launched in the year of 2000 which was focussed on privatization of the power network and electricity market with main objective to discontinue the monopoly of the Iranian government. This resulted in good way with 48.05% shares are achieved by the private sector in annual energy generation till the year of 2015. Rahmat *et al*. [14], has introduced a combination of alternating current (AC) supported model of transmission expansion planning (TEP), considering the reactive power planning (RPP). Main goals of this planning model include the minimization of investment cost while maximization of the social benefits. The expected energy not supplied (EENS) index was applied to improve the reliability of the system. Monte carlo simulation method has been utilized for the determination of the EENS. Particle Swarm Optimization (PSO) scheme used to solve the planning issues, which have been observed in the nonlinear mixed integer optimization method. A detailed study for the design and implementation of the system protection scheme (SPS) for Kawai-Kalisindh-Chhabra Thermal Complex in the Rajasthan state of India is reported in [15]. An optimized approach for the restructuring of the Rajasthan transmission network to cater load demand of the Rajasthan's Refinery and Petrochemical Complex is reported in [16]. A transmission line protection scheme using Wigner distribution function (WDF) and alienation coefficient is reported in [17], and implemented for the protection of grid in the presence of solar [18] and renewable energy [19].

A study to analyze the operation of dynamic line rating (DLR) system for the overhead transmission line operated at high voltage is introduced in [20]. It is established that the DLR is accurate and effective to increase the line capacity, and reduce the risk of line overheating during all the loading and weather conditions. In [21], authors proposed the unified power flow controller (UPFC) for the control of real and, reactive power flows on the transmission line at both the ends. A method for the determination of maximum power transfer capabilities of the electric transmission system using the coupling dynamic line ratings and temperature-dependent line modeling is introduced in [22]. This method avoided the use of the set of predefined, conservative weather conditions and considered uniformity along line. In [23], authors proposed a new design to integrate solar collectors with the cogeneration system of electricity and freshwater. Thermodynamic modeling is used for the gas power plant. It increased the efficiency of the proposed power plant from 35% to 46%. A transient simulation model of solar-assisted heating and cooling systems (SHCs) for a duplex house in the Iran is proposed by the authors in [24]. The maximum cooling load and auxiliary gas-fired boiler are used to design the cooling capacity of the absorption chiller and the solar collector area. A detailed study for the optimization and analysis of the combined cycle power plant [25], energy and economic analysis of desalination system with brine tank [26] and reverse osmosis desalination integrated with geothermal energy [27] are reported in the mentioned literatures. By detailed analysis of the above discussed literature review, it is pointed out that the optimization approaches are required for the restructuring of the practical power system network. It is considered as the focussed topic in this article. Hence, following are the main contributions of this article:

- An optimized approach for the restructuring of the network associated with the thermal complexes in the Rajasthan State of India is introduced to mitigate power evacuation constraints.
- Effectiveness of the proposed restructuring of the power system network is analysed by creating various 400/220 kV GSS and 220/132 kV GSS in the region.
- Research also considered replacement of existing interconnecting transformers (ICTs) at thermal power stations (TPS) by higher ratings.
- An optimized option is suggested for the alterations in the existing transmission system of the Rajasthan, India to mitigate evacuation constraints of the thermal power stations.

The contents of the article are arranged in seven sections. The Section 2 details the base test system, thermal complexes considered for the study and problem formulation. Proposed optimized network restructuring approach is elaborated in the Section 3. Methods of the load flow and short circuit studies are detailed in the Section 4. Simulation results of the load flow study are presented in the Section 5 whereas the Section 6 details the simulation results of the short circuit study. Concluding remark is provided in the Section 7.

2. Proposed test system and problem formulation

This section details the thermal complexes, transmission system associated with the thermal complexes and base test system used for the study. Problem formulation and objective of the study are also discussed in this section.

2.1. Thermal complexes and associated transmission system

The thermal complexes situated in the Kota and Baran regions of the Rajasthan include Kalisindh thermal power station (TPS), Kawai thermal power station, Chhabra thermal power station and Chhabra super critical thermal power station (SCTPS). The details of these thermal complexes with generation capacity are tabulated in Table 1 [28]. There is a 765 kV (kilo volt) GSS situated at Anta. These thermal complexes are connected to 765 kV Grid-substation (GSS) Anta with the help of 400 kV Transmission lines. Transmission system rated at 220 kV is used to connect these thermal complexes with load centers in the region. Important 220kV GSS include 220 kV GSS Jhalawar, Modak, Bhawanimandi, Kawai, Baran and Dahra. Power map of this region is illustrated in Figure 1 [29]. For power evacuation from the thermal power plants mentioned in the Table 1, there is a pooling substation at Anta, which is rated at the voltage level of 765 kV. This 765 kV GSS is connected to the thermal power plants with the help of 400 kV transmission lines. At 765 kV GSS Anta, there are 3 x 1500 MVA, 400/765 kV transformers used to step up the power, which is transmitted through 765 kV GSS Phagi to the load centres. Transmission lines used for the power evacuation from thermal power plants are described in the Table 2 [29].

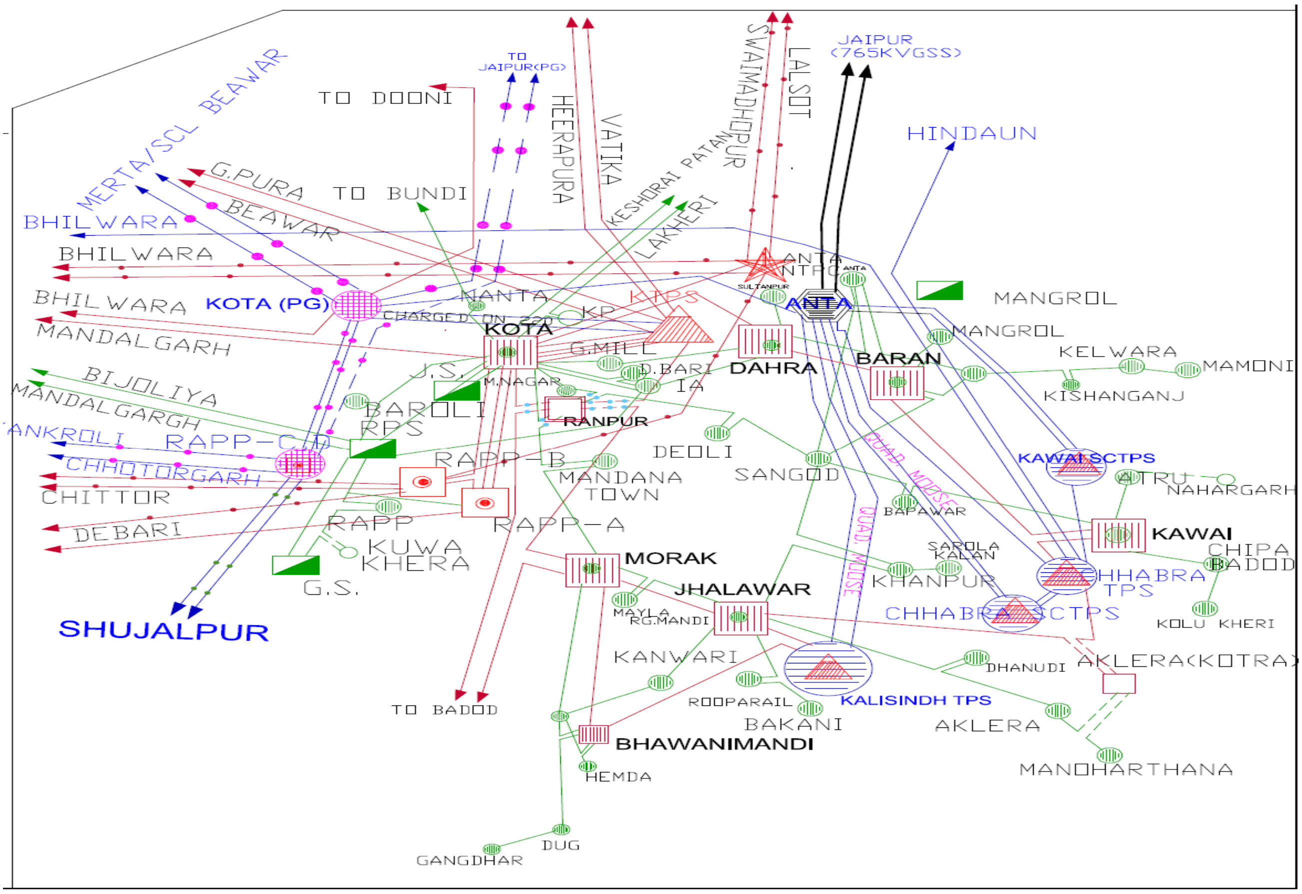

Figure 1. Thermal complexes and associated transmission system.

In addition to the transmission lines mentioned in Table 2, there are step down transformers used to cater load in the region. Transformers rated at 315 MVA, 400/220 kV is installed at Kalisindh TPS with 315 MVA, 400/220 kV ICT is installed at Chhabra TPS. Power from these transformers is evacuated using 220 kV transmission lines to feed the load in the region.

Table 1. Generation capacity of thermal power plants.

S. No.	Name of thermal power plant	Unit No.	Generation capacity (MW)	Total plant capacity (MW)
1	Kalisindh Thermal Power Plant	1	600	1200
		2	600	
2	Kawai Thermal Power Plant	1	660	1320
		2	660	
3	Chhabra Thermal Power Plant (CTPP)	1	250	1000
		2	250	
		3	250	
		4	250	
4	Chhabra Supercritical Thermal Power Plant (CSCTPP)	1	660	1320
		2	660	

Table 2. Details of transmission lines and power transmission capacity.

S. No.	Name of transmission line	Type of conductor	Power transmission capability (MW)	Line length (km)
1	765 kV S/C Anta-Phagi Circuit-I	Bersimis	2250 MW	212 km
2	765 kV S/C Anta-Phagi Circuit-II	Bersimis	2250 MW	214 km
3	400 kV D/C Kalisindh-Anta line	Quad Moose	1215 MW	79 km
4	400 kV D/C Chhabra SCTPS-Anta line	Quad Moose	1215 MW	89 km
5	400 kV S/C Chhabra TPS-Anta line	Twin Moose	515 MW	90 km
6	400 kV D/C Chhabra TPS- SCTPS Chhabra line	Quad Moose	1215 MW	2 km
7	400 kV D/C Kawai SCTPS-Anta Line	Quad Moose	1215 MW	50 km
8	400 kV S/C Kawai SCTPS-Chhabra TPS line	Twin Moose	515 MW	53 km
9	400 kV S/C Chhabra TPS-Hindaun line	Twin Moose	515 MW	305 km
10	400 kV S/C Chhabra TPS-Bhilwara line	Twin Moose	515 MW	303 km
11	400 kV S/C Anta-Kota (PG) line	Twin Moose	515 MW	75 km

2.2. Problem formulation and objective of the study

The main problem faced by transmission system operator is the power generation in the thermal complexes is huge and same is evacuated through the existing 765 kV, 400 kV and 220 kV lines. The existing transmission system is insufficient to evacuate power during the contingency conditions. Existing network supports the N-1 contingency except the tripping of 1500 MVA, 765/400 kV ICT and 765 kV GSS Phagi. The system is not sufficient for the N-1-1 and N-2 contingencies. Hence, additional network or restructuring of the existing network is required to divert the power flow and comply with the N-1-1 and N-2 contingencies. Central electricity authority (CEA) guidelines also forced the STUs that the network complies for N-1-1 and N-2 contingencies. Hence, main aim of this study is to propose optimized restructuring of the power system network so that it comply the N-1-1 and N-2 contingencies for the evacuation of power from thermal complexes.

2.3. Base test system

The existing network of the transmission system with voltage levels equal to and above the 132 kV is considered. This network comprises of conventional generators such as TPPs, nuclear power plants (NPPs) and hydro power plants (HPPs). Renewable energy (RE) is continuously being integrated to the existing network specifically in western parts of the Rajasthan. The existing network consists of transmission lines and GSS rated at voltage levels of 765 kV, 400 kV, 220 kV, and 132 kV. This network contains power system developed by the central transmission utility (CTU) and STU. Rajasthan Rajya Vidhyut Prasaran Nigam Ltd. (RVPN), performs responsibility of STU for the development of transmission network. The Power Grid Corporation of India (PGCIL) performs the responsibility of CTU to develop network of high voltage level (400 kV and above) in India. Following are the important 765 kV GSS owned by the CTU and STU, operating in territory of the Rajasthan [29].

- 765 kV GSS Anta owned by RVPN
- 765 kV GSS Phagi owned by RVPN
- 765 kV GSS Ajmer owned by CTU
- 765 kV GSS Chhitorgarh owned by CTU
- 765 kV GSS Bikaner owned by CTU and under construction
- 765 kV GSS Khetri owned by CTU and under construction
- 765 kV GSS Bhadla-I & II owned by CTU and under construction
- 765 kV GSS Fatehgarh-I under construction by tariff based competitive bidding (TBCB)
- 765 kV GSS Fatehgarh-II under construction and owned by CTU

Table 3. Grid substation statistics (in numbers).

S. No.	Voltage level	RVPN	PPP (RVPN)	PGCIL	Total
1	765 kV	2	0	2	4
2	400 kV	16	2	9	27
3	220 kV	121	1	0	122
4	132 kV	436	15	0	451
Total		575	17	11	603

The existing grid substation inside the Rajasthan as on February 2019 is provided in Table 3 [29]. It include the 765 kV GSS, 400 kV GSS, 220 kV GSS and 132 kV GSS. The 33 kV and 11 kV GSS are owned by the distribution companies and these are constructed according to the load demand. Extra high voltage (EHV) substations are constructed by RVPN, PGCIL and under the scheme of public private partnership (PPP). The transformer capacity at EHV grid substation inside the Rajasthan as on February 2019 is detailed in the Table 4 [29]. Generation available from the conventional generators, central sector projects and RE sources are 12086.5 MW, 15085.83 MW and 12641.965 MW, respectively [29].

Table 4. Transformation capacity (MVA).

S. No.	Voltage level	RVPN	PPP (RVPN)	PGCIL	Total
1	765 kV	7500	0	6000	13500
2	400 kV	12625	1260	7855	21740
3	220 kV	29875	0	0	29875
4	132 kV	31345	375	0	31720
Total		81345	1635	13855	96835

3. Proposed optimized network restructuring approach

To perform the optimized approach for the restructuring of the transmission network to mitigate power evacuation constraints associated with the thermal complexes; various proposals have been framed, looking to minimum lengths of the lines to minimize cost and right of way (RoW) problems for constructing the proposed transmission lines. It has also been taken into consideration that the proposed new transmission system will help to meet the requirement of N-1, N-1-1 and N-2 contingencies as desired by the CEA. Here, the contingency condition refers to the outage of the one or more lines. As per the grid code guidelines of the central electricity regulatory commission (CERC), the transmission utility should comply with the N-1, N-1-1 and N-2 contingency conditions for the generators [30]-[31]. Hence, the possible proposals have taken care of the N-1, N-1-1 and N-2 contingency conditions. Line-in-line-out (LILO) lines simply indicate that circuit of the existing line is broken from a point and these new points are taken to the new location. Following are the feasible proposals identified to mitigate the power evacuation problem associated with the thermal complexes.

3.1. Proposal-1: 400/220 kV ICT at 765 kV GSS anta and 220 kV GSS at Sangod

There are buses of 765 kV and 400 kV voltage levels at existing 765 kV GSS Anta, where power is stepped up to 765 kV from the 400 kV. There is no downstream network at the existing 765 kV GSS Anta. Hence, the main advantages of this proposal is, it will reduce the loadings on one 765 kV line from the Anta to Phagi. The execution time for this proposal will be minimum. The cost of the proposal will also be minimum because it will not involve the construction of 400 kV voltage level network except the 2 × 500 MVA, 400/220 kV ICT at Anta. It will also have the advantage that it will directly feed the power to three 220 kV GSS namely 220 kV GSS Dahra, 220 kV GSS Bara and 220 kV GSS Anta (proposed). Hence, this proposal is easy to implement and involves the minimum cost of framing by considering the 400/220 kV ICT at 765 kV GSS Anta and creation of 220/132 kV GSS at Sangod with following transmission system.

- 2 × 500 MVA, 400/220 kV ICT at 765 kV GSS Anta.
- 1 × 165 MVA, 220/132 kV ICT at 220 kV GSS Sangod (Proposed).
- 44 km 220 kV S/C transmission line from 765 kV GSS Anta to 220 V GSS Dahra.
- 6 km 220 kV D/C power line from 765 kV GSS Anta to 220 V GSS Baran.
- 35 km 220 kV D/C power line from 765 kV GSS Anta to 220 V GSS Sangod (Proposed).
- 10 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Bapawari at 220 kV GSS Sangod (Proposed).

- 8 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Khanpur at 220 kV GSS Sangod (Proposed)

This proposal has the major disadvantage that, if the space available at the 765 kV GSS Anta is utilized for the development of 400 kV system then the future expansion of 765 kV network will not be possible. Electrically, this proposal is feasible but looking to the space constraints it would be better to use alternative proposals.

3.2. Proposal-2: 400 kV GSS at dahra and 220 kV GSS at Sangod

At Dahra, existing 220 kV GSS can be upgraded to 400 kV GSS by utilizing the existing 220 kV and 132 kV networks. An additional line to 220 kV GSS Baran from the proposed 400 kV GSS Dahra will increase the power supply reliability in the region. The proposed 400 kV GSS at Dahra will help to meet the load of region as well as it will support the system in the contingency conditions. The proposed 220 kV GSS at Sangod will help to cater load in the nearby region. This proposal involves an additional 400 kV line development. Hence, a proposal, which is feasible to frame can be developed by considering the creation of 400/220 kV GSS at Dahra and 220/132 kV GSS at Sangod with following transmission system.

- 2 × 500 MVA, 400/220 kV Transformer at 400 kV GSS Dahra (Proposed).
- 1 × 165 MVA, 220/132 kV Transformer at 220 kV GSS Sangod (Proposed).
- 30 km 400 kV D/C line from 765 kV GSS Anta to 400 kV GSS Dahra (Proposed).
- 44 km 220 kV D/C line from 400 kV GSS Dahra (Proposed) to 220 V GSS Baran.
- 48 km 220 kV D/C line from 400 kV GSS Dahra (Proposed) to 220 V GSS Sangod (Proposed).
- 10 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Bapawari at 220 kV GSS Sangod (Proposed)
- 8 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Khanpur at 220 kV GSS Sangod (Proposed)

This proposal mitigate the problem of space constraints. However, it involves the cost higher than proposal-1 considering the creation of 400 kV voltage system at 765 kV GSS Anta.

3.3. Proposal-3: 400 kV GSS at Sangod

In this proposal, creation of 400/220/132 kV GSS at Sangod has been considered. The load growth in the Sangod region has been increased significantly in the last 5 years. It forced the utility to develop additional transmission system in the region to meet the increasing demand. Hence, in all the proposals, the creation of 220 kV GSS at Sangod has been considered. Hence, a proposal considering the 400 kV and 220 kV Voltage levels at the same location has been considered. Since, there is also a problem of overloading of 315 MVA, 400/220 kV ICT at Klisindh thermal power station, this proposal would help to reduce the loading on ICT at Kalisindh TPS. Hence, a proposal, which is feasible to frame, can be considered the creation of 400/220 kV GSS at Sangod with the 220/132 kV ICT at the same location with following transmission system.

- 2 × 500 MVA, 400/220 kV Transformer at 400 kV GSS Dahra (Proposed).
- 1 × 165 MVA, 220/132 kV Transformer at 220 kV GSS Sangod (Proposed).
- 35 km LILO of one circuit of 400 kV D/C line from Kalisindh TPS to 765 kV GSS Anta.
- 35 km 220 kV D/C line from 220 kV GSS Sangod (Proposed) to 220 V GSS Baran.

- 10 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Bapawari at 220 kV GSS Sangod (Proposed)
- 8 km LILO of 132 kV S/C line from 132 kV GSS Sangod to 132 kV GSS Khanpur at 220 kV GSS Sangod (Proposed)

This proposal also helps to mitigate the problem of space constraints. However, it involves the cost higher than the proposal-1, considering the creation of 400 kV voltage system at 765 kV GSS Anta. This proposal is effective to support the system in the N-1, N-1-1 and N-2 contingency condition desired by the CEA.

4. Simulation using MiPower software

Feasibility of the proposed different alternatives is investigated using the load flow and short circuit studies. These studies are carried out using the MiPower software. The network of the STU discussed in the section 2 has been modeled in the MiPower software using the graphical user interface. The details of the conductors reported in transmission planning criteria of the CEA are used for designing the transmission lines of different voltage levels [30]. Brief discussion of the load flow and short circuit studies are also included in this section.

4.1. Load flow study

Technical feasibility of the possible proposals has been investigated with the help of load flow study (LFS). These studies are performed for the total load of 14430 MW for financial year (FY) 2021-22 [30]. Projected load is decided by the central electricity regulatory commission for the particular state. For Rajasthan state, the projected load corresponding to the year 2021-22 is equal to 14430 MW. In the region, considered for this study, wind and solar power generations are low and thermal generation is high. Hence, the proposed study is carried out in the conditions of low wind and solar power generations (25%). During low wind and solar power generation scenarios, power is not exported to the interstate tie lines due to the load generation balance in the state itself. Hence, the loads representing the power transfer on the interstate tie lines (ISTS) have been switched OFF, which is tabulated in Table 5.

Table 5. Load reflected at ISTS buses.

S. No.	Name of bus	Voltage level	Load (MW)
1	400 kV GSS Zerda	400 kV	600 MW
2	400 kV GSS RAPP-D	400 kV	900 MW
3	765 kV GSS Chhitorgarh	765 kV	270 MW
4	765 kV GSS Phagi	765 kV	750 MW
5	765 kV GSS Bikaner	765 kV	2000 MW

Load flow study (LFS) has been performed using the fast decoupled method. It is carried out for the base case described in the section 2.3 and various proposals described in the section 3. Load flow study for the base case and all the feasible proposals has been carried out by considering the normal generations of wind and solar power (25%) to test strength of the proposed transmission system. Following five contingency conditions have been considered corresponding to all the proposed cases.

Contingency 1: 400 kV, D/C Quad Moose power line of 2 km length between Chhabra TPS and Chhabra Super-critical TPS is kept closed. In normal conditions, the CEA has approved this line to be kept open circuited looking to the loading on the 400 kV bus of Chhabra TPS. This is N-1 contingency.

Contingency 2: Outage of 400 kV, S/C Twin Moose power line from 765 kV GSS Anta to 400 kV GSS Kota (Power Grid) is considered. This is N-1 contingency.

Contingency 3: Outage of 400 kV, S/C Twin Moose power line from Chhabra TPS to 400 kV GSS Hindaun is considered. This is N-1 contingency.

Contingency 4: Outage of one circuit of 765 kV, S/C Quad Bersimis line from 765 kV GSS Anta to 765 kV GSS Anta line is considered. This is N-1 contingency.

Contingency 5: Outage of 400 kV, S/C Twin Moose power line from Chhabra TPS to 400 kV GSS Hindaun and 400 kV, S/C Twin Moose line from Chhabra TPS to 400 kV GSS Bhilwara are considered. This is N-1-1 contingency, if outage of lines occurs one by one and this is N-2 contingency, if simultaneous outage of both lines is considered.

4.2. Short circuit study

Protection system of the transformers, transmission lines and generators is based on the short circuit levels. Currents allowed during short circuit are 50 kA. Hence, a short circuit study of base case and all proposals described have been carried out for investigating impacts of restructuring on the levels of short circuit of the system. This will help to take necessary revision in the existing protection system, if required. System protection scheme (SPS) of the thermal complexes in the region is the main protection used to protect the transmission system during the contingency conditions. Hence, utmost care should be taken, while adding any new element in the region. Hence, short circuit study will help to meet the requirement of the protection system.

5. Simulation results of load flow study

Results related to the load flow study for the restructuring of the Rajasthan transmission system in the Kota-Baran region, to mitigate power evacuation constraints in the thermal complexes and meet the increased load demand in the region. The load flow results considering the normal wind and solar power generations (25%) are presented in this section. Load flow results related to the base case without considering the proposed network are also included in this section. The normal range of the voltage is the voltage between the 97% to the 103% of the rated value. Further, for the power rating of the transmission lines, the normal range in the loading is up to Surge impedance loading (SIL). For the transformers, the loading up to the rated capacity is considered normal range. Observations supported by the load flow results are also presented in this section.

5.1. Load flow study for base case

LFS has been performed without considering the 400/220 kV ICT at 765 kV GSS Anta, 400 kV GSS at Dahra, 400 kV GSS at Sangod and 220 kV GSS at Sangod and considering the existing network in the Barana, Kota and Jhalawar districts along with the whole transmission system of the

Rajasthan state including the transmission system of CTU, existing in the territory of Rajasthan. Central sector generators operating in the Rajasthan state have also been considered. Plots of power flow are achieved from LFS for the base case is depicted in Figure 2**.** The load flow on important transformers, in the region under consideration is provided in Table 6. It can be observed that the 315 MVA, 400/220 kV ICT at Kalisindh TPS is overloaded. Further, loading on the transformers at 220 kV GSS Kawai and Baran is also high. The loading on 315 MVA, 400/220 kV ICT at Chhabra TPS is further high. Since loading on the 315 MVA, 400/220 kV ICT at Kalisindh TPS is high, hence an alternate proposal for the replacement of 315 MVA ICT by 500 MVA, 400/220 kV ICT at Chhabra TPS is also recommended and included in all the proposals. Further, one circuit of the Jhalawar-Kalisindh TPS is T-off at 220 kV GSS Bhawani Mandi. Hence, removal of this T-off by the construction of additional bay at Kalisindh TPS is considered.

Table 6. Results of load flow on transformers with base case and proposed cases.

S. No.	Transformer details	Load Flow (MW)			
		Base Case (Exhibit-1)	Proposal-1 (Exhibit-2)	Proposal-2 (Exhibit-3)	Proposal-3 (Exhibit-4)
1	4500 MVA, 765/400 kV ICT at 765 kV GSS Anta	2020	1810	1805	1816
2	315 MVA, 400/220 kV ICT at Chhabra TPS	292	153	203	171
3	315 MVA, 400/220 kV ICT at Kalisindh TPS	306	385	457	418
4	1000 MVA, 400/220 kV ICT at Dahra (Proposed)	-	-	418	-
5	1000 MVA, 400/220 kV ICT at Anta (Proposed)	-	513	-	-
6	1000 MVA, 400/220 kV ICT at Baran (Proposed)	-	-	-	454
7	200 MVA, 220/132 kV ICT at Dahra	76	110	126	85
8	200 MVA, 220/132 kV ICT at Bara	150	184	145	163
9	200 MVA, 220/132 kV ICT at Kawai	139	115	111	109
10	320 MVA, 220/132 kV ICT at Bhawani mandi	119	122	113	110
11	200 MVA, 220/132 kV ICT at Modak	66	84	50	45
12	160 MVA, 220/132 kV ICT at Ranpur	80	45	79	74
13	260 MVA, 220/132 kV ICT at Jhalawar	137	156	147	143
14	160 MVA, 220/132 kV ICT at Sangod (Proposed)	-	97	81	130

The load flow on important transmission lines in the region under consideration is provided in Table 7. Reactive power flow in transmission lines has not been considered because it does not play significant role in the power system planning. As far as power system planning is considered, the active power flow is important factor. It can be observed that the loading on the 400 kV S/C Anta-Kota (PG) line is near to the thermal loading, which is considered to be high for the normal system operating conditions. Loading on the 220 kV Chhabra TPS- Kawai line is also very high and it is operating above the thermal loading of the line. Loading on the other 400 kV and 220 kV lines in the region is quite high and most of the lines are operating above the SIL. Hence, this existing system will not support in the contingency conditions. Total system (transmission) loss for the base case without considering the proposed network, is provided in Table 8. It can be observed that the system loss is equal to 503.203 MW. The study of base case, presented in this section, will act as reference for the proposed cases to select a feasible proposal for mitigating power evacuation problem associated with the thermal complexes.

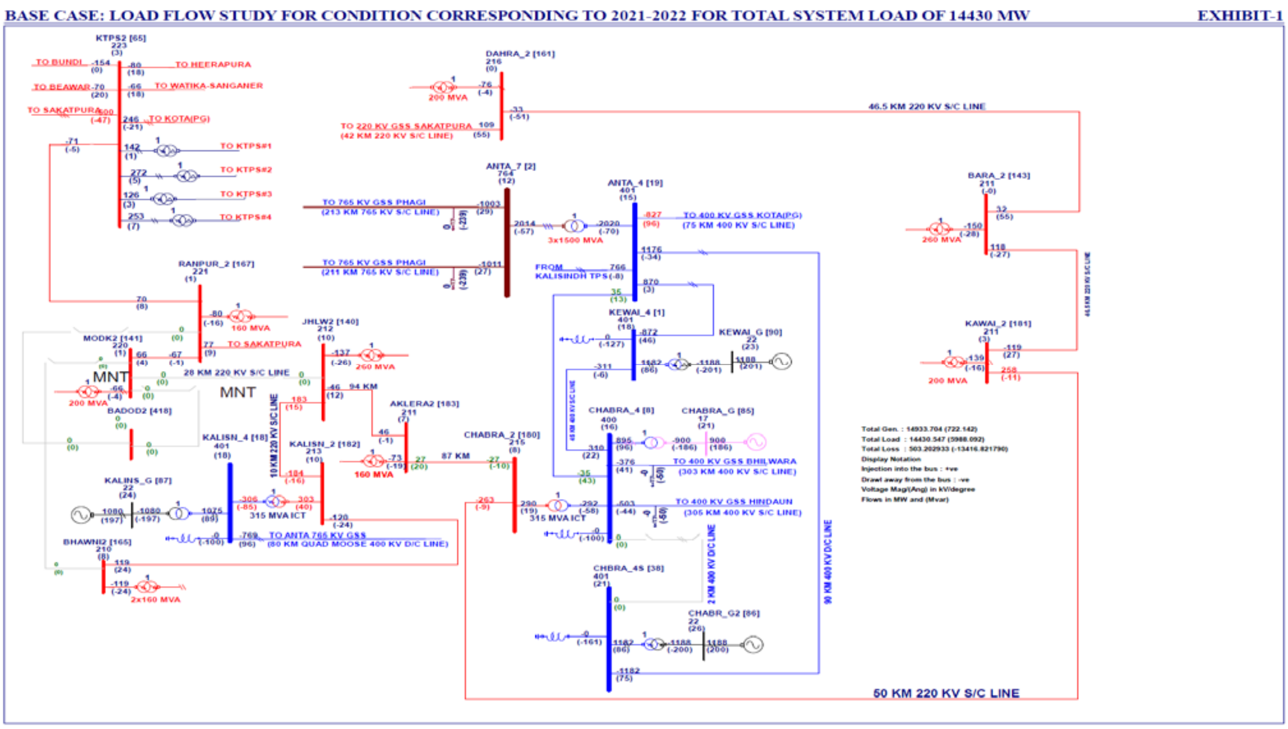

Figure 2. Power flow plots for base case.

Table 7. Load flow on transmission lines with base case and proposed cases.

S. No.	Transmission line details	Power flow (MW)			
		Base Case (Exhibit-1)	Proposal-1 (Exhibit-2)	Proposal-2 (Exhibit-3)	Proposal-3 (Exhibit-4)
1	765 kV Anta-Phagi Circit-I	1003	899	896	902
2	765 kV Anta-Phagi Circit-II	1011	906	904	910
3	400 kV D/C Chhabra SCTPS-Anta line	1182	1182	1182	1182
4	400 kV D/C Chhabra SCTPS-Chhabra TPS line	0	0	0	0
5	400 kV S/C Chhabra TPS-Hindaun line	503	487	48	487
6	400 kV S/C Chhabra TPS-Bhilwara line	376	345	339	345
7	400 kV S/C Chhabra TPS-Anta line	35	108	93	101
8	400 kV S/C Chhabra TPS-Kawai TPS line	−310	−198	−221	208
9	400 kV D/C Kawai TPS-Anta line	872	984	961	974
10	400 kV S/C Anta-Kota (PG) line	827	629	620	633
11	400 kV D/C Kalisindh TPS-Anta line	769	689	618	281
12	400 kV D/C Anta-Dahra line (Proposed)	-	-	418	-
13	400 kV S/C Anta-Sangod line (Proposed)	-	-	-	79
14	400 kV S/C Kalisindh-Sangod line (Proposed)	-	-	-	375
15	220 kV S/C Kalisindh TPS-Bhawani Mandi Line	120	118	134	136
16	220 kV D/C Kalisindh TPS-Jhalawar Line	184	265	320	279
17	220 kV S/C Jhalawar-Modak Line	0	88	140	158
18	220 kV S/C Jhalawar-Aklera Line	46	21	33	-
19	220 kV S/C Modak-Ranpur Line	−66	0	110	136
20	220 kV S/C Modak-Bhawani Mandi Line	0	4	−20	25
21	220 kV S/C Ranpur-Skatpura Line	−77	-19	30	51
22	220 kV S/C Ranpur-KTPS Line	−70	-27	0	10
23	220 kV S/C Chhabra TPS-Aklera Line	27	47	56	47
24	220 kV S/C Chhabra TPS-Kawai Line	263	106	146	124

Continued on next page

S. No.	Transmission line details	Power flow (MW)			
		Base Case (Exhibit-1)	Proposal-1 (Exhibit-2)	Proposal-2 (Exhibit-3)	Proposal-3 (Exhibit-4)
25	220 kV S/C Kawai-Baran Line	119	−10	33	14
26	220 kV S/C Baran-Dahra Line	−32	97	−54	109
27	220 kV S/C Anta-Dahra Line (Proposed)	-	122	-	-
28	220 kV D/C Anta-Sangod Line (Proposed)	-	98	-	-
29	220 kV S/C Anta-Baran Line (Proposed)	-	292	-	-
30	220 kV S/C Dahra-Sangod Line (Proposed)	-	-	81	-
31	220 kV Dahra-Baran Circuit-II (Proposed)	-	-	57	-
32	220 kV S/C Sangod-Baran Line (Proposed)	-	-	-	259
33	220 kV S/C Sangod-Jhalawar Line (Proposed)	-	-	-	22

Table 8. Total system losses with base case.

S. No.	Transformer details	Base Case (Exhibit-1)	Proposal-1 (Exhibit-2)	Proposal-2 (Exhibit-3)	Proposal-3 (Exhibit-4)
1	Total System losses (MW)	503.203	493.726	501.816	494.782
2	Saving of Losses (MW)	-	9.477	1.387	8.421
3	Energy Saving (LU/annum)	-	358.64	52.488	318.677

5.2. Load flow study for the proposed case-1: 400/220 kV ICT at 765 kV GSS anta and 220 kV GSS at Sangod

LFS is carried out by considering the 400/220 kV ICT at 765 kV GSS Anta, and 220 kV GSS at the Sangod and considering the existing network in the Barana, Kota and Jhalawar districts along with the transmission system of Rajasthan state, including the transmission system of the CTU, existing in the territory of Rajasthan. Central sector generators operating in the Rajasthan state are also considered. Plots of power flow achieved from LFS for the proposed case are described in Figure 3. The load flow of the transformers in the region is provided in Table 6. It can be observed that the 315 MVA, 400/220 kV ICT at Kalisindh TPS would be overloaded but the loading on the proposed 500 MVA, 400/220 kV ICT at Kalisindh would be in the permissible limit (zero loading to rated capacity). Further, loading of the transformers at Kawai is also high. The loading on 315 MVA, 400/220 kV ICT at Chhabra TPS is reduced significantly. The removal of this T-off by the construction of additional bay at Kalisindh TPS is also considered in this proposal.

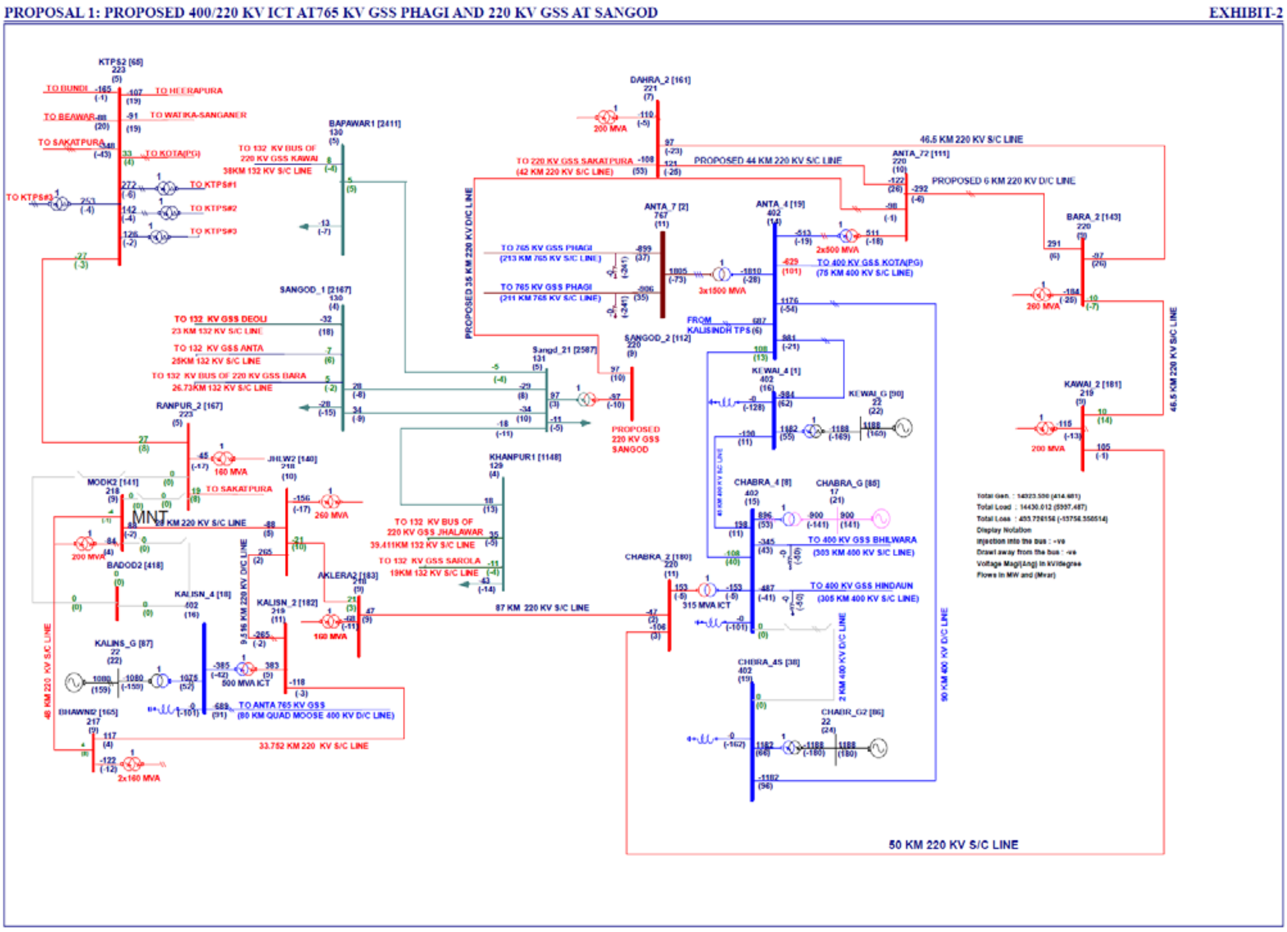

Figure 3. Power flow plots for proposed case-1.

The load flow of the important, existing and proposed transmission lines in the region for the proposed case-1 is tabulated in Table 7. Reactive power flow in the transmission lines has not been considered because it does not play significant role in the power system planning because power system planning considered active power flow as key factor. The transmission lines include the 765 kV, 400 kV and 220 kV lines. The 132 kV lines have not been considered because their loading depends only on the load they feed. It can be observed that loading on the 400 kV S/C Anta-Kota (PG) line has been reduced significantly. Loading on the 220 kV Chhabra TPS- Kawai line is also reduced significantly. Loading on all other 400 kV and 220 kV lines, in the region, is reduced significantly and operating near the surge impedance loading (SIL). Network is also tested for the contingency conditions. LFS is performed for the contingency conditions-1, 2, 3, 4 and 5. It is observed that in the event of contingency-1, loads on all the lines, in the region, are normal and existing network along with the proposed network is found to be stable in all respects. In the contingency-2 condition, loading on the 400 kV CTPS-Hindaun line and 220 kV Anta-Dahra line is increased. Loading on the 315 MVA, 400/220 kV ICT is also high. On all the lines and transformers, the loading is normal (below rated capacity). In the contingency-3 condition, loading on the 400 kV S/C Anta-Kota (PG) line is high and line is operating above SIL but below thermal loading. Loading on 220 kV D/C Kalisindh-Jhalawar line is high. The lines 220 kV S/C Jhalawar-Modak, 220 kV Modak-Ranpur, 220 kV S/C Chhabra TPS-Kawai are operating above SIL. In the contingency-4 condition, loading on the 400 kV S/C Anta-Kota (PG) line is high and line is operating above SIL but below thermal loading. Loading on the 220 kV D/C Kalisindh-Jhalawar line is high. The lines 220 kV S/C Jhalawar-Modak, 220 kV Modak-Ranpur, 220 kV S/C Chhabra TPS-Kawai are operating above SIL. In the contingency-5 condition, loading on the 400 kV S/C Anta-Kota (PG) line is very high and line is operating near the thermal loading. Loading on the 220 kV D/C Kalisindh-Jhalawar line is high. The lines 220 kV S/C Jhalawar-Modak, 220 kV Modak-Ranpur, 220 kV S/C Chhabra TPS-Kawai are operating above SIL.

The total system (transmission) loss for the test system, with transmission system for the proposal-1 is provided in Table 8. It can be observed that the system losses are equal to 493.726 MW. It is further observed that total saving in loss is equal to 9.477 MW and energy saving of 358.64 LU/annum is achieved with the proposed case-1 by considering an additional 400/220 kV ICT at 765 kV GSS Anta and creation of 220 kV GSS at Sangod.

5.2.1. Benefits of proposed Case-1

Following are important benefits associated with the proposal-1, observed from LFS and financial analysis.

(a) Total system losses would reduce with a saving of 9.477 MW or 358.64 Lus/Annum.
(b) Proposed case 1 would be the cheapest proposal.

5.2.2. Drawback of the proposed Case-1

Based on the study presented above, following are the important drawbacks associated with the proposal-2

(a) With installation of 400/220 kV transformer at 765/400 kV Anta GSS, will expose the 400 kV bus to the frequent faults that would occur on 220 kV systems and they will directly travel to generating power systems connected to this bus.
(b) There is no space in alignment of 400 kV bus at Anta to accommodate an additional 400 kV transformer bay, hence 400 kV bus would be extended (L shape) and bus sectionaliser will be used between 765/400 kV and 400/220 kV switchyard at 400 kV.
(c) Construction of 220 kV bus bar arrangement at 765 kV Anta GSS is possible only in the space reserved for the future two numbers of 765 kV bays i.e., further 765 kV interconnections would be eleminated.

5.3. Load flow study for the proposed Case-2: 400 kV GSS at dahra and 220 kV GSS at Sangod

LFS is performed by considering creation of 400/220 kV GSS at Dahra and 220/132 kV GSS at Sangod using interconnections as detailed in the section 3.2. The existing network in the Rajasthan includes the transmission system of CTU, existing in the territory of Rajasthan in addition to the creation of 400/220 kV GSS at Dahra and 220/132 kV GSS at Sangod. Central sector generators operating in the Rajasthan state have also been considered. Power plots obtained using LFS for the proposed case-2 with normal wind and solar power generation (25%) is placed at Figure **4**. The load flow of important transformers in the region under consideration is provided in Table 6. It can be observed that the 315 MVA, 400/220 kV ICT at Kalisindh TPS would be overloaded but the loading on the proposed 500 MVA, 400/220 kV ICT at Kalisindh would be within normal range. Further, loading on all other transformers is within the range. The loading of 315 MVA, 400/220 kV ICT at Chhabra TPS is reduced significantly. The removal of this T-off by the construction of additional bay at Kalisindh TPS is also considered in this proposal.

The load flow of the important, existing and proposed transmission lines in the region under consideration, for the proposed case-2, is provided in Table 7. The reactive power flow of transmission lines has not been considered because it does not play important role in the power system planning, as power system planning considered the active power flow an important factor. The transmission lines include the 765 kV, 400 kV and 220 kV lines. The 132 kV lines have not been considered because their loadings depend only on the load they feed. It can be observed that loading on the 400 kV S/C Anta-Kota (PG) line has been reduced significantly and it is operating slightly above the SIL. Loading on the 220 kV D/C Jhalawar-Kalisindh line is high. Further, Loading on the 220 kV Chhabra TPS- Kawai line is also reduced significantly and it is operating slightly above the SIL. The 220 kV S/C Jahalawar-Modak line is also operated above SIL. Loading on other 400 kV and 220 kV lines in the region is reduced significantly and lines are operating near the surge impedance loading (SIL). The network is also tested for the contingency conditions. The power flow plots for the contingency conditions-1, 2, 3, 4 and 5 are investigated. It is observed that in the event of contingency-1, loadings on all the lines in the region are normal and existing network along with the proposed network is found to be stable in all respects. In the contingency-2 condition, the 400 kV CTPS-Hindaun line is operating near the SIL. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is high. Loadings on all the lines and transformers are normal and below the rated capacity. Loadings on the 220 kV D/C Jhalawar-Kalisindh line, 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are high. In the contingency-3 condition, the 400 kV S/C Anta-Kota (PG) line is operating above SIL and just below the thermal loading. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is high. Loadings on all the lines and transformers are normal and below the rated capacity. Loading on the 220 kV D/C Jhalawar-Kalisindh line is high. Loadings on 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are quite high and above the SIL. In the contingency-4 condition, the 400 kV S/C Anta-Kota (PG) line is operating above the SIL and just below the thermal loading. Further, loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is high. On all the lines and transformers, the loading is normal. Loading on the 220 kV D/C Jhalawar-Kalisindh line is high and operating near the thermal loading. Loadings on 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are quite high and above the SIL. In the contingency-5 condition, the 400 kV S/C Anta-Kota (PG) line is operating near the thermal loading. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is high. On all the lines and transformers, the loading is normal. Loading on the 220 kV D/C Jhalawar-Kalisindh line is high and operating near thermal loading. Loadings on 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are quite high and above the SIL.

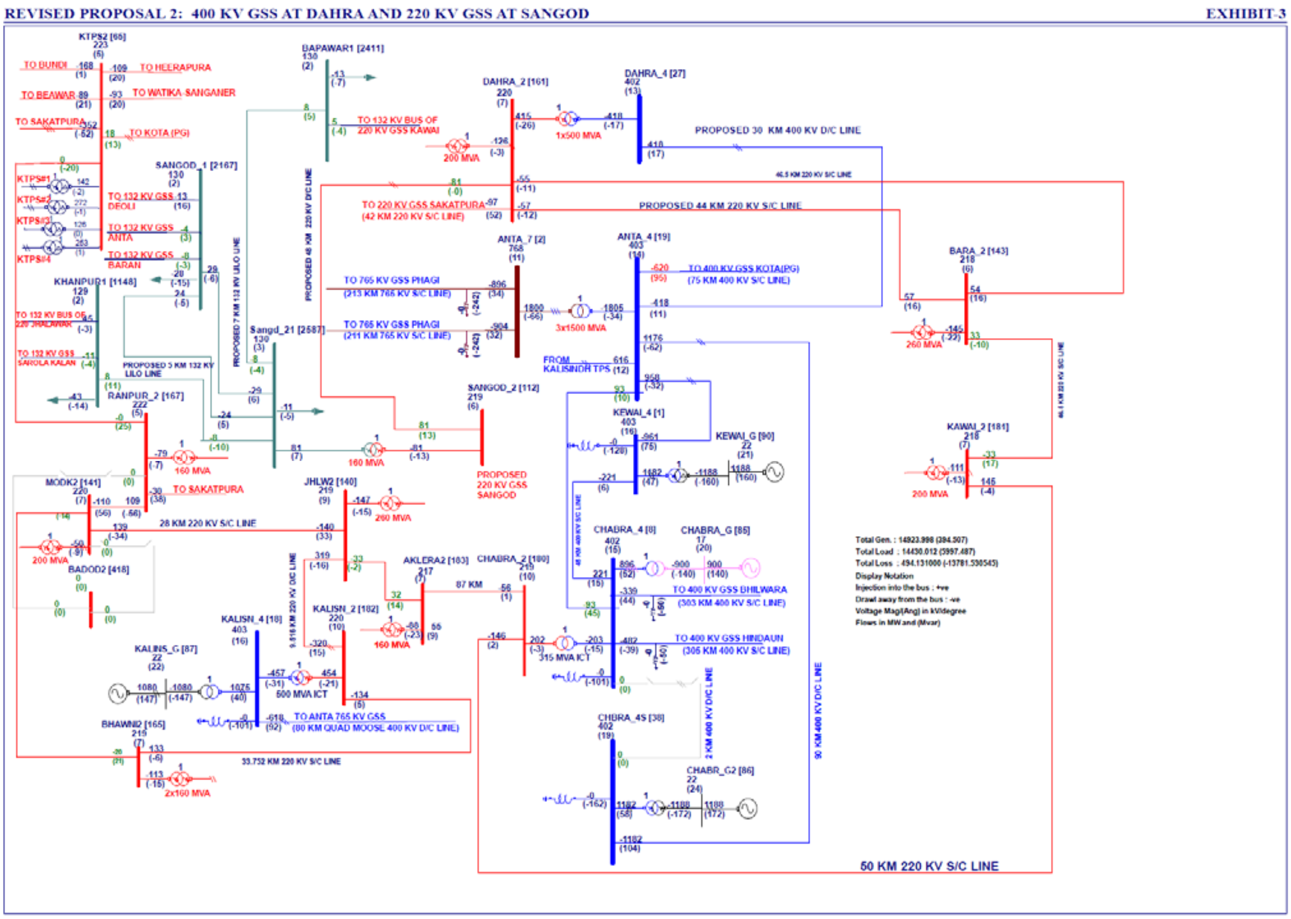

Figure 4. Power flow plots for proposed case-2.

Total system (transmission) loss for the test system with the transmission system for the proposal-2 is provided in Table 8. It can be observed that the system losses are equal to 501.816 MW. It is further observed that the total saving of losses is equal to 1.387 MW and energy saving of 52.488 LU/annum is achieved with the proposed case-2 by considering an additional 400/220 kV at Dahra and creation of 220 kV GSS at Sangod.

5.3.1. Benefits of the proposed Case-2

Based on the study presented above, following are the important benefits associated with the proposal-2.

(a) Total system losses would reduce with the saving of 1.387 MW or 52.488 LU/Annum.
(b) Land bank is available at 220 kV Dahara GSS.
(c) Since 400 kV D/C Chhabra-Anta(765 kV)/Bhilwara line is in the vicinity of the proposed GSS, hence in future only termination of these lines at the 400 kV gantry would be required.

5.3.2. Drawback of the proposed Case-2

Based on the study presented above, following are the main drawbacks associated with the proposal-2.

(a) 400 kV D/C (twin Moose) line from Chabbra TPS to Bhilwara/Anta (765 kV) are falling within the boundary of 220 kV Dahar GSS. So two towers would have to be dismantled.
(b) 400 kV control room would be constructed after dismantling of quarters/colony.
(c) Proposed case 2 would be the costliest proposal.

5.4. Load flow study for the proposed Case-3: 400 kV GSS at Sangod

LFS is carried out by considering the creation of 400/220/132 kV GSS at Sangod with interconnections as detailed in the section 3.3. The existing network in the Rajasthan includes the transmission system of CTU, existing in territory of the Rajasthan along with the creation of 400/220/132 kV GSS at Sangod. Central sector generators operating in the Rajasthan state have also been considered. Plots of power flow, obtained using LFS for the proposed case-3 with normal wind and solar power generations (25%) are placed at Figure 5. The load flow of the important transformers in the region is provided in Table 6. It can be observed that the 315 MVA, 400/220 kV ICT at Kalisindh TPS would be overloaded but loading on the proposed 500 MVA, 400/220 kV ICT at Kalisindh would be within normal range. Further, loading on all other transformers is within the range. The loading on 315 MVA, 400/220 kV ICT at Chhabra TPS is reduced significantly compared to the base case. The removal of this T-off by the construction of an additional bay at Kalisindh TPS is also considered in this proposal.

Load flow of the existing and proposed transmission lines in the region for the proposed case-3 is provided in Table 7. The transmission lines include the 765 kV, 400 kV and 220 kV lines. It can be observed that loading on the 400 kV S/C Anta-Kota (PG) line has been reduced significantly and it is operating slightly above the SIL. Loading on the 220 kV D/C Jhalawar-Kalisindh line is normal. Loading on the 220 kV Chhabra TPS- Kawai line is also reduced significantly and it is operating below the SIL. The 220 kV S/C Jahalawar-Modak line is also operated slightly above the SIL. Loading on the other 400 kV and 220 kV lines in the region, is reduced significantly and lines are operating near the surge impedance loading (SIL). The network is also tested for the contingency conditions.

The power flow plots for the contingency conditions-1, 2, 3, 4 and 5 are investigated. It is observed that in the event of contingency-1, loads on all the lines, in the region are normal and existing network along with the proposed network is found to be stable in all respects. In the contingency-2 condition, the 400 kV CTPS-Hindaun line is operating near the SIL. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is normal, if 500 MVA ICT is considered. On all the lines and transformers, the loading is normal. Loadings on the 220 kV D/C Jhalawar-Kalisindh line, 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are quite high and these lines are operating above SIL. In the contingency-3 condition, loading on the 400 kV S/C Anta-Kota (PG) line is high and operating below the thermal loading but above the SIL. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is normal, if 500 MVA ICT is considered. On all the lines and transformers, the loading is normal. Loadings on all the lines and transformers are normal and below the rated capacity. Loadings on the 220 kV D/C Jhalawar-Kalisindh line, 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are quite high and these lines are operating near the SIL. In the contingency-4 condition, loading on the 400 kV S/C Anta-Kota (PG) line is high and operating below the thermal loading but above the SIL. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is normal, if 500 MVA ICT is considered. On all the lines and transformers, the loading is normal. Loadings on the 220 kV D/C Jhalawar-Kalisindh line, 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are normal and these lines are operating near the SIL. In the contingency-5 condition, loading on the 400 kV S/C Anta-Kota (PG) line is high and operating near the thermal loading. Loading on the 500 MVA, 400/220 kV ICT at Kalisindh TPS is normal, if 500 MVA ICT is considered. Loadings on all the lines and transformers are normal and below the rated capacity. Loadings on the 220 kV D/C Jhalawar-Kalisindh line, 220 kV S/C Jhalawar-Modak line, 220 kV S/C Modak-Ranpur line and 220 kV S/C CTPS-Kawai line are normal and these lines are operating near the SIL.

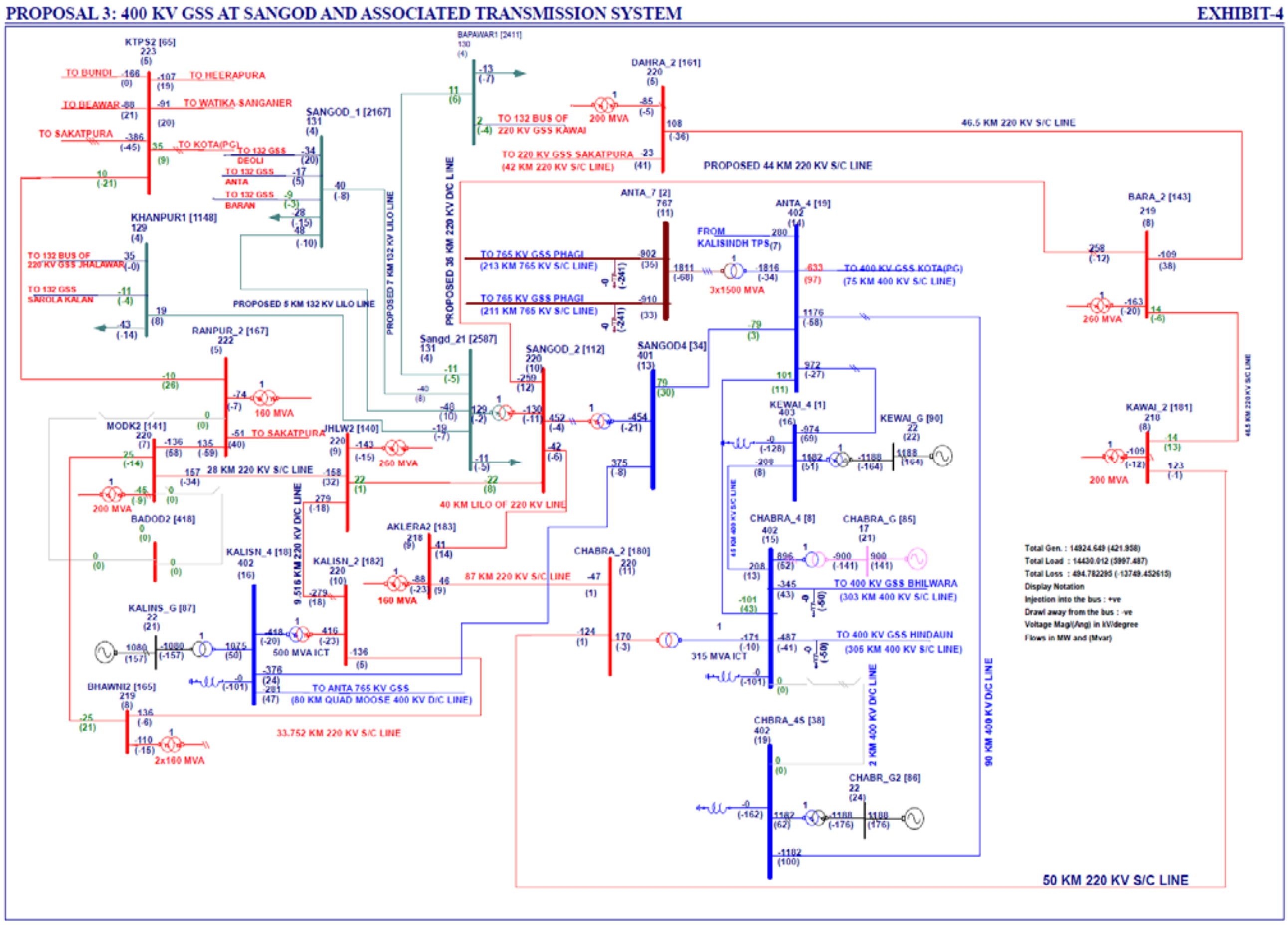

Figure 5. Power flow plots for proposed case-3.

The total system (transmission) loss for the test system by considering the transmission system for the proposal-3 is provided in Table 8. It can be observed that the system losses are observed to be 494.782 MW. It is further observed that the total saving of losses equal to 8.421 MW and energy saving of 318.677 LU/annum have been achieved with the proposed case-3 by considering an additional 400/220 kV ICT at 765 kV GSS Anta and creation of 220 kV GSS at Sangod.

5.4.1. Benefits of the proposed Case-3

Based on the study presented above, following are the main drawbacks, associated with the proposal-3.

(a) Total system losses would reduce with the saving of 8.421 MW or 318.677 LUs/Annum. The proposed cases envisaged maximum saving.
(b) 400 kV D/C Kalisindh TPS-Anta (765 kV) line can be used to provide the inter-connectivity to the proposed 400 kV GSS at Sangod. This will obviate laying of long 400 kV lines from 765/400 kV Anta GSS.

5.4.2. Drawback of the Proposed Case-3

Based on the study presented above, following are the important benefits associated with the proposal-3.

(a) New land has to be identified and selected.

5.5. Observations

Based on the study presented in this section, following are the important observations are made:

- The existing and new transmission system is sufficient for all N-1-1/N-2 contingencies except when both 765 kV 2xS/C Anta- Phagi line are out.
- 1x500 MVA, 400/220 kV ICT at Kalisindh TPS and 3 nos. of 220 kV circuits are overloaded and 400 kV S/C Anta-Kota (PG) are overloaded to 1499 MW.
- The loading on the 1x500 MVA, 400/220 kV ICT at Kalisindh TPS has reduced as compared to the similar contingency in proposed case-1.
- Overloading of 400 kV S/C Anta-Kota (PG) can be obviated by bypassing at 765/400 kV GSS Anta.
- The overloading of 400/220 kV ICT at Kalisindh TPS can be avoided by opening of 220 kV Modak-Ranpur circuit and 220 kV S/C Jhalawar Modak line.
- By creating new 400/220 kV switchyard at Sangod will help to reduce the loading on 220 kV lines in the regions under contingency conditions compared to the proposed case-1.
- This will also help to avoid any constraints for the future expnasion at 765 kV GSS Anta.
- Total system losses would reduce from 503.203 MW to 493.407 MW, thus saving of approximate 9.796 MW (370.712LUs/Annum).
- Therefore, it is concluded that creation of 400/220 kV GSS at Sangod will be technically more suitable and feasible compared to the 400 kV switchyard at 765 kV GSS Anta and 220 kV GSS Sangod.

6. Simulation results of short circuit study

Results of the short circuit study for the proposed restructuring of Rajasthan transmission system in the Kota-Baran region to mitigate the power evacuation constraints associated with the Kalisindh-Kawai-Chhabra thermal complexes for investigating the effects of proposed transmission system on the protection schemes are presented in this section. Short circuit results, related to the base case without considering the proposed network are also presented in this section. The short circuit study for all the proposed cases is also presented in this section.

6.1. Short circuit study for the base case

The results related to the short circuit study for base case, without considering the creation of the proposed 220 kV GSS and 400 kV GSS in the region is carried out and short circuit MVA as well as short circuit current are presented in Table 9. These will be considered as reference for the proposed cases to justify the requirements of the protection system in terms of the short circuit levels. It is inferred that short circuit fault current on all the buses, in the region is below 50 kA, which is the permissible limit of the fault level for the protection equipments. These values will be taken as reference values for the various proposed cases.

Table 9. Short circuit levels for base case and proposal-1.

Bus No.	Bus name	Rated voltage (kV)	Base case		Proposal-1	
			3-Phase MVA	Fault current (kA)	3-Phase MVA	Fault current (kA)
1	400 kV Kawai	400	18831.600	27.182	19147.477	27.638
2	765 kV Anta	765	18204.394	13.739	18608.736	14.045
4	765 kV Phagi	765	17326.632	13.077	17444.875	13.166
8	400 kV Chhabra	400	14707.899	21.230	14772.175	21.322
17	400 kV Phagi	400	20792.501	30.012	20837.278	30.077
18	400 kV Kalisindh	400	13187.201	19.035	13686.436	19.755
19	400 kV Anta	400	23994.415	34.634	25174.750	36.338
38	400 kV Chhabra Supercritical	400	13416.528	19.366	13596.850	19.626
140	220 kV Jhalawar	220	2207.005	5.792	3913.900	10.272
141	220 kV Modak	220	3045.313	7.992	2697.808	7.080
143	220 kV Baran	220	2699.935	7.992	7551.188	19.817
161	220 kV Dahra	220	3716.323	9.753	5778.139	15.164
165	220 kV Bhawani Mandi	220	1528.217	4.011	2617.508	6.869
167	220 kV Ranpur	220	6353.178	4.011	6479.383	17.004
180	220 kV Chhabra	220	3243.038	8.511	3564.635	9.355
181	220 kV Kawai	220	2518.161	6.609	3265.804	8.571
182	220 kV Kalisindh	220	2440.264	6.404	4208.873	11.046
183	220 kV Kotra	220	1720.204	4.514	2025.670	5.316
417	220 kV Anta	220	6136.185	16.104	6171.153	16.196
111	220 kV Anta	220	-	-	8330.338	21.862
112	220 kV Sangod	220	-	-	4204.387	11.034

6.2. Short circuit study for the proposed Case-1

The results of short circuit study for the proposed case-1 by considering the creation of proposed 220 kV GSS at Sangod and 400/220 kV ICT at 765 kV GSS Anta is carried out and short circuit MVA as well as short circuit current are presented in Table 9. It can be observed that short circuit fault current on all the buses is below 50 kA. Hence, the proposal-1 is technically feasible for the creation of new transmission system in the region to mitigate the power evacuation constraints of the Kalisindh-Kawai-Chhabra thermal complexes.

6.3. Short circuit study for proposed Case-2

Table 10. Short circuit fault level for proposal-2 and proposal-3.

Bus No.	Bus Name	Rated Voltage (kV)	Proposal-2		Proposal-3	
			3-Phase MVA	Fault Current (kA)	3-Phase MVA	Fault Current (kA)
1	400 kV Kawai	400	18550.017	26.775	18263.466	26.362
2	765 kV Anta	765	18585.404	14.027	18289.384	13.804
4	765 kV Phagi	765	17445.710	13.167	17345.840	13.091
8	400 kV Chhabra	400	12719.832	18.360	12622.638	18.220
17	400 kV Phagi	400	20718.177	29.905	20667.404	29.832
18	400 kV Kalisindh	400	14118.311	20.379	13082.507	18.884
19	400 kV Anta	400	24900.218	35.941	24081.292	34.759
38	400 kV Chhabra SCTPS	400	13556.101	19.567	13430.118	19.385
140	220 kV Jhalawar	220	5071.456	13.310	5563.220	14.600
141	220 kV Modak	220	4816.404	12.640	4972.286	13.049
143	220 kV Baran	220	4111.752	10.791	5404.165	14.183
161	220 kV Dahra	220	6922.415	18.167	4504.587	11.822
165	220 kV Bhawani Mandi	220	3295.531	8.649	3396.797	8.915
167	220 kV Ranpur	220	7690.187	20.182	7670.535	20.131
180	220 kV Chhabra	220	3373.806	8.854	3442.073	9.033
181	220 kV Kawai	220	2883.153	7.567	3020.774	7.928
182	220 kV Kalisindh	220	5316.749	13.953	5663.455	14.863
183	220 kV Kotra	220	1880.074	4.934	2248.997	5.902
417	220 kV Anta	220	6178.000	16.214	6166.379	16.183
27	220 kV Dahra	220.000	15109.215	21.809	-	-
112	220 kV Sangod	220.000	3377.647	8.864	10917.396	15.758
34	400 kV Sangod	400	-	-	7274.757	19.092

The results of short circuit study for the proposed case-2 considering the creation of proposed 220 kV GSS at Sangod and 400/220 kV GSS Dahra is carried out and short circuit MVA as well as short circuit current are presented in Table 10. It is observed that the short circuit fault current on all the buses in region is below 50 kA. Hence, the proposal-2 is technically feasible for the creation of the new transmission system in the region to mitigate the power evacuation constraints of the Kalisindh-Kawai-Chhabra thermal complexes.

6.4. Short circuit study for the proposed Case-3

The results of short circuit study for the proposed case-3 by considering the creation of proposed 400/220/132 kV GSS at Sangod is carried out and short circuit MVA as well as short circuit current are presented in Table 10. It is evaluated that short circuit fault current on all the buses in the region is below 50 kA. Hence, the proposal-3 is technically feasible for the creation of the new transmission system in the region to mitigate the power evacuation constraints of the Kalisindh-Kawai-Chhabra thermal complexes.

7. Conclusions

This paper presented a detailed study to propose an optimized restructuring of the Rajasthan transmission system in the Kota-Baran region to mitigate power evacuation constraints of the thermal complexes. Study is carried out for the base case of the Rajasthan transmission system and three different proposals. Proposal-1 has considered the creation of 400/220 kV ICT at 765 kV GSS Anta, and 220 kV GSS at Sangod. Proposal-2 has considered the creation of 400/220 kV at Dahra and creation of 220 kV GSS at Sangod. Proposal-3 has considered the creation of 400/220/132 kV GSS at Sangod. It is established that systems losses of 503.203 MW, 493.726 MW, 501.816 MW, and 494.782 MW are observed for the base case and proposals-1, 2 & 3 in respective order. All the three proposals meet out the requirement of system fault levels. Proposal-1 is not feasible for execution considering the future expansion planning of the network. Hence, based on the results of the detailed load flow study, short circuit study, system constraints and requirement of network expansion in future, it is concluded that the creation of 400/220 kV GSS at Sangod along with the revised interconnections at Kalisindh TPS will be technically the most effective and feasible option to mitigate the power evacuation constraints associated with the thermal power plants. This study is aimed to improve the performance of real time utility transmission grid and would be greatly useful for the research community to investigate modifications in the power system network.

Conflict of interest

The authors declare no conflict of interests.

Declaration by the authors

The authors declare that contents included in this article are purely scholarly ideas of the authors. These are not related to any organizations. However, the data used in the article have been properly referred.

Author contributions

The authors declare that all authors have contributed equally.

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