A High Voltage Test System Meeting Requirements under Normal and All Single Contingencies Conditions of Peak, Dominant, and Light Loadings for Transmission Expansion Planning Studies

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***Abstract*— This paper introduces a new 17-bus 500 kV test system that has been specially designed to support transmission expansion planning studies. Unlike other test systems that have been developed for power system analysis, this system is unique because it focuses exclusively on transmission expansion planning at high voltage levels. Existing test systems that are used for TEP studies, in combination with electricity market problems or for integrating new generation or loads, tend to consider the system operations only under normal conditions and one loading condition. However, in practical scenarios, the system must be able to operate under different loading conditions and single contingencies to ensure reliability. Therefore, a reliable test system should mimic the behavior of a real power system, operating under both normal and all single contingency conditions for different loading conditions. This paper addresses this need by introducing a 17-bus 500 kV test system that can operate successfully under three different loading conditions (peak load, dominant load - 60% of peak load, and light load - 40% of peak load), while also being able to handle the operation at normal and single contingency conditions in each case.**

Keywords—Power system, test system, transmission expansion planning, normal condition, single contingency, peak load, dominant loading, light loading.

I. Introduction

In the ever-evolving landscape of the power industry, power system restructuring has brought profound shifts in both demand and generation systems. Despite the integration of energy-saving technologies and demand response strategies in modern power distribution systems, the relentless upward trajectory of load demand persists. As outlined in the 2022 Western Assessment of Resource Adequacy report of Western Electricity Coordinating Council (WECC) [1], there is an anticipated 11.4% increase in collective demand across the entire U.S. Western connection from 2023 to 2032. The composition of the future generation is poised for substantial transformation compared to the past, largely dominated by the renewable resources because of the mandated Renewable Portfolio Standards (RPS) aimed at decarbonization, which entails that utilities and power providers must procure a defined portion of their electricity from renewable sources [2]. Given the continuous rise in energy consumption and the growing incorporation of substantial renewable resources into the main grid, it is imperative to establish a resilient and reliable power grid. A 2021 study focused on achieving net-zero emissions in the United States by 2050 revealed the necessity to enhance the capacity of high-voltage transmission lines by approximately 50% by 2030 and threefold by 2050 [3]. In this regard, a base test system at the transmission levels is crucial for TEP research including comparing different planning formulations, scenarios, and optimization techniques, and benchmarking optimal approaches.

Few test systems at transmission voltage levels have been suggested for the TEP studies, some examples are a six-bus Garner test system [4], the HRP-38 bus system designed for the TEP with high renewable energy penetration [5], and the 46-bus southern Brazilian system [6]. The IEEE 24 test system is found to be the most used in TEP research, for example [7, 8].

There are also some test systems for the expansion planning and efficient reconfiguration of networks with distributed generators [9, 10], and some test systems for system expansion planning with reliability evaluations [11, 12]. In [13], a test system for network expansion planning with n-1 contingencies has been proposed. However, all the aforementioned test systems are for distribution voltage level, not for transmission voltage level (>230 kV), or are for other types of studies that do not need to be considered single contingencies and different loading conditions.

TEP scenarios should reliably operate under both normal condition as well as all single contingencies for different loading conditions from peak load to light load. The limitations of existing test systems lie in their ability to meet operational requirements exclusively under normal condition, while their performance under all single contingencies remains uncertain. This raises concerns regarding the validity of TEP outcomes. In this regard, ensuring/examining acceptable operation under all single contingencies for the existing test systems mentioned above is very complex, especially for large ones. The situation becomes more challenging if the test system cannot meet requirements under any of single contingencies, since there are no straightforward solutions to fixing that test system, just a trial and error approach involving adjustments such as new

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lines, load and generation changes, and shunt reactors or capacitors modifications. Note that each change may address a contingency, but may also lead to violations for other contingencies or normal conditions, necessitating a lot of load flow analysis for each change.

This research paper introduces a new test system that has been designed specifically for transmission expansion planning (TEP) studies at a high transmission voltage of 500 kV. The test system has been carefully designed to meet voltage drop and line loading requirements under normal conditions, as well as all single contingencies for three different loading conditions – peak load, dominant load, and light load. Section II of the paper provides all the necessary information about the test system. Load flow results for the three different loadings are presented in sections III and IV, respectively, under both normal and single contingency conditions. Finally, section V summarizes the key findings and contributions of this paper.

II. Information on Test System

A. Power System Topology

Fig. 1 displays a simplified single line diagram representation of the test system, consisting of a total of 17 buses. The swing bus is Bus 1, while Buses 3, 6, 8, 10, 12, 13, and 15 are classified as voltage-controlled buses (PV buses), with the remaining buses identified as load buses (PQ buses). The positioning of the buses in Fig. 1 is assumed to reflect their geographical locations, and the exact measurements of the transmission line lengths connecting them have been measured and documented in Table I.

The assumed length for line 7-12 was 300 km, forming the reference for determing the lengths of other lines. It is important to highlight that the connection between buses 1 and 2 involves two lines, with the length specified in Table I representing each line. This applies to other instances of double-line connections between buses as well. The system voltage for this test system is 500 kV.

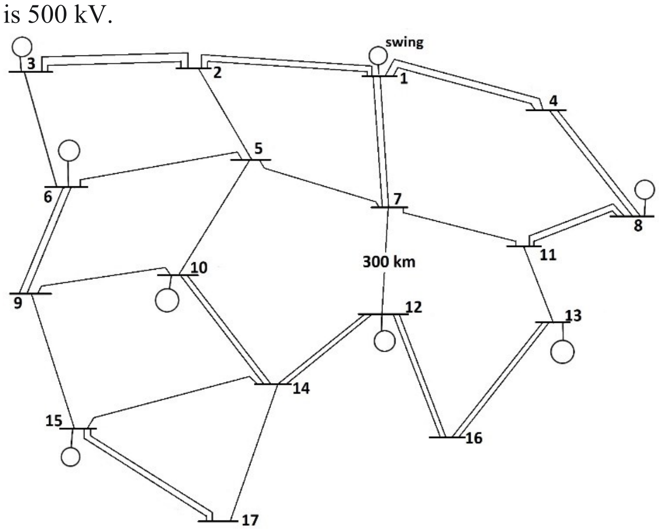

Fig. 1. Single line diagram of the 17-bus test system for TEP studies.

B. Transmission Line Configuration

The configuration of transmission line for the proposed 500 kV test system is shown in Fig. 2.

TABLE I. RANSMISSION LINES LENGTH IN 17-BUS TEST SYSTEM

Line	Length(km)	Line	Length (km)
1-2	410.32	7-12	300.00
1-4	426.77	8-11	349.09
1-7	370.91	9-10	447.27
2-3	436.90	9-15	398.18
2-5	294.55	10-14	392.73
3-6	349.55	11-13	261.29
4-8	416.13	12-14	348.38
5-6	415.20	12-16	406.45
5-7	435.48	13-16	417.27
5-10	376.36	14-15	458.18
6-9	316.36	14-17	403.64
7-11	387.09	15-17	402.16

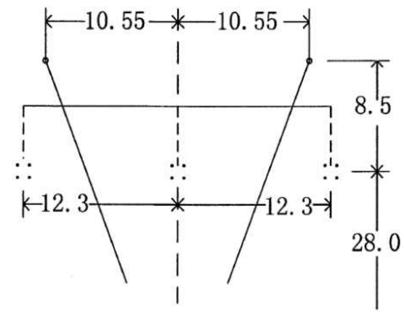

Fig. 2. Configuration transmission lines for the test system.

It is important to note that each circuit of line 1-2 holds the same configuration and arrangement shown in Fig. 2 which is customary for transmission lines operating at this voltage level. Essentially, line 1-2 is composed of two circuits, each positioned on separate towers rather than being on a single tower. As shown in Fig. 2, the line is configured horizontally (flat) and maintains aphase spacing of 12.3 m at an elevation of 28 m above the ground level. Each phase includes four bundled sub-condutors and chosen conductor type for this line is Macaw. This is configuration is based on an actual 500 kV conventional line [14]. The detailed information of conductors and computed line parameter are shown in Table II.

TABLE II. CONDUCTOR INFORMATION AND LINE PARAMETERS OF TEST SYSTEM

Conductor and Bundle Information			Line Parameters	
Type	4 × Macaw		R (Ω/km)	0.0228
Outside diameter of the conductor (inches)	1.055		L (mH/km)	0.878
Subconductor spacing(m)	0.45		C (nF/km)	12.975

C. Generations, Loads, and Shunt Compensators at Peak Load

Bus 1 is the slack bus, and its voltage magnitude, $|V_1|$=1.05 p.u. and voltage angle, δ_1=0 at peak load condition. Voltage magnitude information for voltage-controlled buses at peak loading conditions and active power rating of each generating units are presented in Table III. A typical assumption applied to all voltage controlled buses, particularly those in conventional power plant with synchronous generating units, is to consider

Q_{gmax}= 0.6P_g and Q_{gmax}= 0.3P_g, a commonly adopted practice by utilities to perform power flow analysis for TEP.

TABLE III. GENERATION INFORMATION OF THE 17 BUS TEST SYSTEM AT PEAK LOAD

Bus (Type)	|V| (p.u.)	P_g (MW)	Q_{gmin} (Mvar)	Q_{gmax} (Mvar)
Bus 3 (PV)	1.05	3600	-1080	2160
Bus 6 (PV)	1.05	3600	-1080	2160
Bus 8 (PV)	1.05	3600	-1080	2160
Bus 10 (PV)	1.05	3600	-1080	2160
Bus 12 (PV)	1.05	3600	-1080	2160
Bus 13 (PV)	1.05	3600	-1080	2160
Bus 15 (PV)	1.00	2500	-1050	2100

The test system cpmprises a total of 16 loads, linked to every bus except the swing bus. The assumption is made that each of these loads operates with a 0.9 lagging power factor. Additionally, the system also integrates fixed shunt compensators, including both shunt reactors and shunt capacitors that are connected to different buses. Detailed information on the loads and shunt compensators connected to various buses during peak loading conditions is presented in Table IV. All shunt compensating devices needed for the peak load conditions are shunt capacitors connected to each load bus, and their magnitude varies from 50 Mvar at bus 7 and bus 9 to 350 Mvar at bus 9. The total capacity of connected shunt capacitors is 1100 Mvar.

TABLE IV. LOAD AND SHUNR COMPENSATION DATA FOR THE TEST SYSTEM AT PEAK LOAD

Bus	Load		Fixed Shunt Capacitors (Mvar)
	P_L (MW)	Q_L (Mvar)	
Bus 2	1920.00	929.89	100
Bus 3	1750.00	847.56	---
Bus 4	1880.00	910.52	100
Bus 5	1600.00	774.92	100
Bus 6	1700.00	823.34	---
Bus 7	1930.00	934.74	50
Bus 8	1600.00	774.92	---
Bus 9	2000.00	968.64	350
Bus 10	1700.00	823.34	---
Bus 11	1800.00	871.77	200
Bus 12	1600.00	774.92	---
Bus 13	1800.00	871.77	---
Bus 14	2300.00	1113.94	---
Bus 15	1700.00	823.35	---
Bus 16	1740.00	842.72	50
Bus 17	1110.00	537.59	150

III. POWER FLOW ANALYSIS

Examining power flow results under both normal operating conditions and various single contingency conditions is pivotal for planners. This analysis aids in pinpointing areas susceptible to congestion, voltage violations, and potential reliability concerns. The acquired insights are instrumental in making well-informed decisions regarding the expansion of the transmission infrastructure. This section delves into the power flow analysis carried out on the test system under normal conditions and all single contingency scenarios across peak, dominant, and light loading. The results of these analyses are then analyzed to identify potential issues regarding voltage drops and areas prone to congestion.

A. Normal Operating Condition.

AC power flow analysis problem is formulated as

$$I = Y_{bus}V \tag{1}$$

$$P_i + jQ_i = V_i I_i^* \tag{2}$$

$$P_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\delta_i - \delta_k - \theta_{ik}) \tag{3}$$

$$Q_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\delta_i - \delta_k - \theta_{ik}) \tag{4}$$

where $|V_i|$ and δ_i are the magnitude and phase angle of the voltage at bus i, n denotes the number of buses in the network, $|Y_{ik}|$ and θ_{ik} are the magnitude and angle of the element of bus admittance matrix, Y_{bus}. P_i and Q_i are the injected real and reactive power into the bus i.
Constraints for performing power flow analysis are:

$$0.95 \leq |V_i| \leq 1.05\, p.u. \tag{5}$$

$$-0.3P_{gi} \leq Q_{gi} \leq 0.6P_{gi} \tag{6}$$

$$S_{ik} \leq S_{ik}^{max} \tag{7}$$

Eq. (5) shows the voltage range that each bus is expected to maintain during normal operation, and Eq. (6) sets the boubdaries for minimum and maximum reactive power generation for each generating unit, contingent on the active power generation, P_{gi}, depicted in Table II. The limit of the power flow in a transmission line connecting bus i and k is given by Eq. (7). Maximum power flow, S_{ik}^{max}, is constrained by the thermal limit of the mentioned line. With four Macaw conductor per bundle, the thermal limit of the line is calculated as $\sqrt{3}$×(500 kV)×(4×0.870 kA) =3014 MVA. The line rating, S_{ik}^{max}, is set at 80% of the thermal limit which isequal to 2400 MVA.

B. Single Contingency Conditions

Power system needs to continue their satisfactory operation even in the event of missing a component, a scenario referred to as a single contingency situation. In TEP studies, the components considered for single contingency analyses typically include transmission lines and transformers. In our test system, the emphasis is on the potential loss of a transmission line. During power flow analysis under each single contingency, Eqs. (1)-(4) and constraints outlined in Eq. (6) and (7) remain applicable. However, for voltage drop considerations, voltage magnitude at all buses needs to have 0.9 p.u., contrary to 0.95 p.u, as in Eq. (8).

$$0.90 \leq |V_i| \leq 1.05\, p.u. \tag{8}$$

IV. POWER FLOW RESULT AND ANALYSIS

A. Peak Load: Normal Operating Condition

To address the power flow issue based on Eqs (1)–(4), the Newton-Raphson method is applied through the PSS/E 35.4

software, utilizing generation and load data from tables III and IV within the test system illustrated in Fig.1. The power flow results of 17 bus test system at peak load are shown in fig. 3, whwre active power flow is represented by green arrows, while orrange arrows signify reactive power flow in lines, loads, and generating units. The load flow results, as presented in Table V, indicate that the per-unit voltage and the reactive power generated by all generating units adhere to the threshold stated in Eqs. (5) and (6). The highest loading lines are: line 2–3 at 32.31%, line 6–9 at 31.42%, line 1–7 at 31.20%, and line 1–7 at 30.84%. Importantly, all of these values remain below the permissible maximum line loading for the transmission lines. This confirms that, under normal condition, the voltage drops and line loading limits are being met.

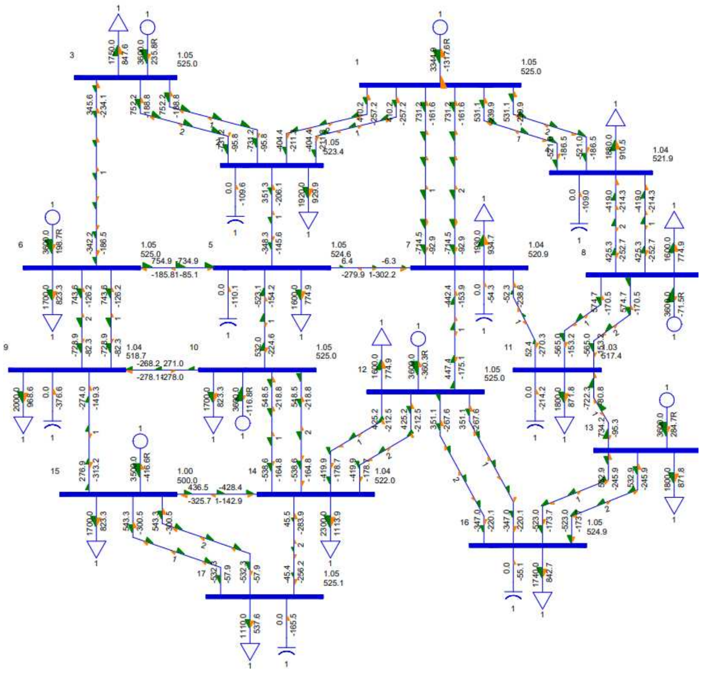

Fig. 3. Power flow result for the test case at peak load under normal operating condition.

TABLE V. POWER FLOW RESULTS OF THE TEST SYSTEM UNDER NORMAL CONDITION AT PEAK LOAD

Bus #	Voltage		Generation	
	$\lvert V\rvert$ $p.u.$	δ (deg.)	P_g (MW)	Q_g (Mvar)
1	1.050	0.00	3344.9	-1317.6
2	1.047	-11.66	0.0	0.0
3	1.050	11.42	3600.0	235.8
4	1.044	-15.79	0.0	0.0
5	1.049	-18.83	0.0	0.0
6	1.050	3.09	3400.0	198.06
7	1.042	-19.00	0.0	0.0
8	1.050	-3.50	3600.0	-71.5
9	1.037	-13.39	0.0	0.0
10	1.050	-4.97	3600.0	-116.8
11	1.035	-17.54	0.0	0.0
12	1.050	-9.69	3600.0	-360.3
13	1.050	-4.13	3600.0	284.7
14	1.044	-19.96	0.0	0.0
15	1.000	-5.15	3500.0	-416.6
16	1.050	-19.55	0.0	0.0
17	1.050	-21.256	0.0	0.0

B. Peak Load: Contingency Condition

For the operation of the test system at peak load under contingency conditions, power flow analysis is conducted for each specific contingency condition, and the outcomes are outlined in Table VI. Each row in the table corresponds to a unique contingency condition. For example, it is considered that one of the two transmission lines connecting bus 1 and bus 2 is out of service in the first row. Under this specific contingency condition, the lowest voltage magnitude of 0.937 p.u. is recorded at bus 2, and the line 1–7 is highly loaded with 33.79% loading.

TABLE VI. SUMMARIZED POWER FLOW RESULTS OF TEST SYSTEM UNDER CONTINGENCY CONDITIONS AT PEAK LOAD

Line outage	Lowest Voltage		The Highest Line Loading	
	$\lvert V\rvert$ $p.u.$	Bus #	% loading	Line
1–2 (1 line)	0.969	2	33.79%	1–7
1–4 (1 line)	0.905	4	36.84%	1–4
1–7 (1 line)	0.963	7	45.84%	1–7
2–3 (1 line)	0.932	2	50.12%	2–3
2–5	0.963	5	34.21%	1–7
3–6	1.000	15	37.19%	2–3
4–8 (1 line)	0.921	4	31.17%	6–9
5–6	0.909	5	40.03%	6–9
5–7	0.972	5	31.64%	6–9
5–10	0.907	5	40.04%	5–6
6–9 (1 line)	0.913	9	54.31%	6–9
7–11	0.987	11	32.13%	2–3
7–12	0.971	7	38.79%	11–13
8–11 (1 line)	0.951	11	40.76%	8–11
9–10	0.950	9	35.30%	6–9
9–15	0.978	9	34.40%	6–9
10–14 (1 line)	0.986	14	35.91%	10–14
11–13	0.951	11	38.95%	7–12
12–14 (1 line)	0.991	14	32.61%	6–9
12–16 (1 line)	0.952	16	32.54%	5–6
13–16 (1 line)	0.937	16	38.16%	11–13
14–15	1.000	15	34.24%	5–6
14–17	0.932	17	32.25%	2–3
15–17 (1 line)	0.900	17	36.09%	15–17

As depicted in Table VI, the most critical contingency arises when one of the lines connecting Bus 15 and Bus 17 is out, resulting in a voltage magnitude of $|V_{17}|$ =0.900 p.u. Other notable severe contingencies occur when one of the line 1–4 is affected, leading to $|V_4|$ =0.905 p.u., or when line 5–6 is disconnected, causing $|V_5|$=0.907 p.u. In terms of line loading, the highest loading percentages, 54.31% and 50.12%, are observed when one of line 6–9 and one of line 2–3 is gone out of service, respectively. The reactive power generation by all generating units remains within acceptable limits and line loadings consistently stay below 50% of threshold for all other individual contingencies. Based on these results, the test system meets the operational criteria under all contingencies.

C. Dominant Load: Normal Operating condition

For the dominant loading conditions, the generation and load values are scaled to 60% of the peak loading condition, and like for peak load, the power factor for all loads is set at 0.9 lagging. For the generating units, each unit's scheduled voltage has been set to 1.0 p.u. while the limits on reactive power generation are taken by the specifications outlined in Eq.(6). The loads and shunt compensator data for this loading condition are provided in Table VII. To ensure the system operates satisfactorily under the dominant loading conditions, a total shunt reactor of 2050 Mvar needs to be connected to different buses as indicated in the table. The shunt capacitors shown in Table IV for peak load condition are all switched off for dominant and light loading conditions.

TABLE VII. LOAD AND SHUNR COMPENSATION DATA FOR THE TEST SYSTEM AT DOMINANT LOAD

Bus	Load		Fixed Shunt Reactor (Mvar)
	P_L (MW)	Q_L (Mvar)	
Bus 2	1152.00	557.93	150
Bus 3	1050.00	508.53	---
Bus 4	1128.00	546.31	50
Bus 5	960.00	464.94	200
Bus 6	1020.00	494.00	---
Bus 7	1158.00	560.84	150
Bus 8	960.00	464.95	150
Bus 9	1200.00	581.18	---
Bus 10	1020.00	494.00	150
Bus 11	1080.00	523.06	---
Bus 12	960.00	464.95	500
Bus 13	1080.00	523.06	---
Bus 14	1380.00	668.36	200
Bus 15	1020.00	494.00	200
Bus 16	1044.00	505.63	100
Bus 17	666.00	322.55	200

Table VIII provides a summary of the power flow result for the test system operating under a dominant load in normal conditions. As shown in the table, each bus voltage magnitude and each generating unit's reactive power remain within the designated thresholds stated in Eqs. (5) and (6). All line loadings are also below their thermal limit, indicating that the test system is operating under normal conditions without any issues.

TABLE VIIII. POWER FLOW RESULTS OF THE TEST SYSTEM UNDER NORMAL CONDITION AT DONIMANT LOAD

Bus #	Voltage		Generation	
	$\|V\|$ $p.u.$	δ (deg.)	P_g (MW)	Q_g (Mvar)
1	1.000	0.00	1945.2	-1972.3
2	1.049	-7.16	0.0	0.0
3	1.000	7.58	2160.0	-358.9
4	1.048	-9.84	0.0	0.0
5	1.046	-11.44	0.0	0.0
6	1.000	2.42	2160.0	-479.1
7	1.045	-11.72	0.0	0.0
8	1.000	-1.83	2160.0	-614.0
9	1.021	-8.07	0.0	0.0
10	1.000	-8.61	1980.0	-546.31
11	1.025	-12.89	0.0	0.0
12	1.000	-5.89	2160.0	-627.2
13	1.000	-2.04	2160.0	-372.3
14	1.046	-12.03	0.0	0.0
15	1.000	-3.04	2100.0	-588.4
16	1.043	-11.88	0.0	0.0
17	1.043	-12.73	0.0	0.0

D. Dominant Load: Single Contingency Conditions

To ensure the operation at contingencies conditions, load flow analysis under all single contingencies is carried out and summarized results are presented in Table IX. Since the total load in this case is less than the peak load, the minimum voltage in each contingency remains comfortably above 0.950 p.u. and line loadings are less than 35%. Based on the result of normal and all single contingencies, the test system at dominant loading conditions meets all the criteria of load flow analysis as well.

TABLE VIIIX. SUMMARIZED POWER FLOW RESULTS OF TEST SYSTEM UNDER CONTINGENCY CONDITIONS AT DOMINANT LOAD

Line outage	Lowest Voltage		The Highest Line Loading	
	$\|V\|$ $p.u.$	Bus #	% loading	Line
1-2 (1 line)	1.000	PV Buses	22.80%	1–7
1-4 (1 line)	0.991	4	22.95%	1–4
1-7 (1 line)	1.000	PV Buses	27.94%	1–7
2-3 (1 line)	1.000	PV Buses	30.57%	2–3
2-5	0.991	5	22.07%	1–7
3-6	1.000	PV Buses	22.91%	2–3
4-8 (1 line)	0.994	4	20.66%	6–9
5-6	0.994	5	25.03%	6–9
5 -7	0.985	5	20.36%	5–6
5-10	0.999	5	25.22%	5–6
6-9 (1 line)	0.976	9	31.19%	6–9
7-11	0.984	11	23.21%	2–3
7-12	1.000	PV Buses	25.19%	11–13
8-11 (1 line)	0.993	11	24.90%	8–11
9-10	0.971	9	21.23%	11–13
9-15	0.976	9	21.55%	11–13
10-14 (1 line)	1.000	PV Buses	23.66%	10–14
11-13	1.000	PV Buses	25.40%	7–12
12-14 (1 line)	1.000	PV Buses	21.76%	11–13
12-16 (1 line)	0.995	16	23.46%	2–3
13-16 (1 line)	0.990	16	24.68%	11–13
14-15	1.000	PV Buses	23.67%	2–3
14-17	0.954	17	23.23%	2–3
15-17 (1 line)	0.965	17	23.48%	2–3

E. Light Load: Normal Operating Condition and Single Contingency Conditions

To mimic the light load operation of the test system, the generation and load values are scaled to 40% of the peak loading condition. Here load power factor is 0.9 lagging. The voltage of each generating unit is set to 1 p.u. All the other operating constraints are as mentioned in Eqs. (5)–(8). The loads and shunt compensators data for this loading condition are provided in Table X. To ensure the system operates satisfactorily under the light loading condition, a total shunt reactor of 6400 Mvar, almost three times that of the dominant loading condition, needs to be connected to different buses as indicated in the table.

Table XI provides the summary of the power flow outcomes for the test system for light load during normal operating conditions. As seen in the table, voltage magnitudes at each bus, along with the generated reactive power of each units, consistently meet the defined thresholds as stated in Eqs. (5) and (6). Also, the system can successfully operate in all single contingencies. The minimum voltage in the system even in the contingency condition is 0.961 p.u. at bus 17 when line 14–17 outage. The line loadings remained comfortably below their designated thermal limits in both normal and all single contingency conditions. Therefore, promising outcome underscores the robustness and operational reliability of the proposed test system under normal condition and all single contingencies for three different loadings. A preliminary version of this test system was first presented in [15] and was used for power system planning studies in [16-18] where the influence of using unconventional lines introduced in [19-23] compared to using conventional lines on resulting in cost saving planning scenarios was discussed.

TABLE X. LOAD AND SHUNR COMPENSATION DATA FOR THE TEST SYSTEM AT LIGHT LOAD

Bus	Load		Fixed Shunt Reactor (Mvar)
	P_L (MW)	Q_L (Mvar)	
Bus 2	768.00	371.95	450
Bus 3	700.00	339.02	150
Bus 4	752.00	351.13	300
Bus 5	640.00	309.96	400
Bus 6	680.00	329.33	400
Bus 7	772.00	373.89	400
Bus 8	640.00	309.96	600
Bus 9	800.00	387.45	100
Bus 10	680.00	329.33	600
Bus 11	720.00	348.71	100
Bus 12	640.00	309.96	900
Bus 13	720.00	348.71	250
Bus 14	920.00	445.57	450
Bus 15	680.00	329.33	650
Bus 16	696.00	337.08	300
Bus 17	444.00	215.03	350

TABLE XI. POWER FLOW RESULTS OF THE TEST SYSTEM UNDER NORMAL CONDITION AT LIGHT LOAD

Bus #	Voltage		Generation	
	$\lvert V\rvert$ $p.u.$	δ (deg.)	P_g (MW)	Q_g (Mvar)
1	1.000	0.00	1275.1	-2025.8
2	1.046	-4.70	0.0	0.0
3	1.000	5.19	2160.0	-412.2
4	1.048	-6.56	0.0	0.0
5	1.047	-7.50	0.0	0.0
6	1.000	1.77	2160.0	-411.5
7	1.048	-7.72	0.0	0.0
8	1.000	-1.13	2160.0	-417.4
9	1.045	-5.16	0.0	0.0
10	1.000	-1.44	1980.0	-427.2
11	1.047	-7.05	0.0	0.0
12	1.000	-3.45	2160.0	-428.2
13	1.000	-1.21	2160.0	-383.7
14	1.050	-7.83	0.0	0.0
15	1.000	-1.76	2100.0	-373.2
16	1.046	-7.78	0.0	0.0
17	1.042	-8.26	0.0	0.0

V. CONCLUSION

In this paper, a 500 kV, 17 bus test system has been introduced specifically for, but not limited to, transmission expansion planning (TEP). Many existing test systems available in the literature have some limitations, either they meet system technical requirements only on normal operating condition, not in all single contingencies or they are for only one loading condition, mainly the peak load. However, a real power system experiences different loading conditions such as peak load, dominant load, and light load. Moreover, the voltage level of most existing test systems is not for the transmission voltage levels (>230 kV), only for the distribution voltage level. However, a test system that can meet all technical operational requirements under different loading conditions and also address all single contingencies is essential for TEP research. This paper bridged this gap by introducing the high voltage test system that meets operational criteria under both conditions for three loading conditions– peak load, dominant load, and light load. The operation of the proposed system was validated by performing power flow analyses under normal and all single contingency conditions in each loading operation.

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