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Voltage Profile Analysis of 132kV Transmission Line Using Powerworld Simulator: A Case Study of JUJA-RABAI Line

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Abstract: The growing power demand has made the government of Kenya to increase it's financial budget to address the issue of transmission and distribution of power. The increasing set up of distribution sub-stations both in urban and rural areas has called for immediate investigation to find out whether the existing transmission lines are capable of handling the load demand without voltage collapse. This paper presents a study to analyze the current voltage profile of Juja-Rabai 132kv transmission lines before new sub-stations are set up to address the growing power demand. The network load flow analysis was carried out using Decoupled load flow analysis method and powerworld software which uses Newton Raphson method. In this study bus voltages of each substation were computed by forming Jacobian matrices. The power flow calculations was used to validate the simulated data. The voltage profile calculations resulted to a flat voltage profile while the simulated results showed violation of voltage profile from Voi Substation to Rabai substation. This violation was corrected using a shunt compensator in Voi substation. This paper revealed that more substations can be terminated in Juja – Rabai 132 kV transmission line to address the existing power demand without voltage violation in the power network.

Keywords: Transmission Line, Voltage Profile, Voltage Collapse, Sub-station

1. Introduction

Industrialization has been the greatest challenge in many countries in Africa. This has been due to its electricity connectivity levels being the lowest in the world. [1]. To realize development, these countries have drafted visions and development plans. The initial step of industrialization is based on having wide and reliable electricity connectivity.

Vision 2030 was set to transform Kenya into an industrialized Nation, which can provide a high quality life to all its citizens. This vision identified energy and electricity as the key element of sustained growth and development [2]. The power utility companies requires high investment in power generation, transmission and distribution. So far the power generation station have been well set up. These includes the hydro power, geothermal power, wind power and solar power. The transmission network has also been established to address the power demand in the country. The greatest challenge in Kenya is the power distribution networks. This implies that, several distribution sub- stations should be established to address the power demand issue.

In Master plan 2012-2017, three hundred distribution sub-staions were to be set up to address the growing power demand in the country. This plan was later extended to be part of the vision 2030 [2]. A study plan of existing transmission and distribution lines should be carried out, in order to find out the reason behind recurrent black outs in Kenyan Networks, before setting up new transmission and distribution lines. This would avoid persistent black outs.

In this paper Powerworld simulator software was used to model Juja-Rabai transmission line. The software was used to study the voltage profile of the network with the current distribution sub-stations before new ones are set up to address the growing power demand. The household electrification disparity is very high in urban and rural areas and this has affected overall productivity and economic environments [3, 4].

The persistent black outs could be due to voltage collapse along the transmission line due to termination of new distribution sub- stations on already overstressed power networks [5].

A stressed power network is prone to power outages, thus limiting distribution network expansions [6].

This study aimed at carrying out voltage profile Analysis of Juja-Rabai 132kv transmission line, which is a 440km long near several upcoming villages. The study also aimed at ascertaining whether the power network can handle extra power load without voltage profile violation. The power utility company stipulates that, A transmission line voltage profile should be maintained at 5% of its rated value [7].

Contribution: This paper presents a voltage profile analysis approach, using fast decoupled power flow calculations and powerworld software simulation. The study provides a means of analyzing existing transmission networks before new lines and new distribution Sub-stations are set up and terminated on existing transmission lines.

Paper Organization: The rest of the paper is organized as follows: Section II gives Literature Review, Section III is the Proposed Methodology, Section IV is Problem Formulation, Section V is the Presentation of Results and Analysis, while Section VI is the Conclusion, Appendices and references used.

2. Literature Review

2.1. Expansion of Transmission Lines

According to the Ministry of energy-Kenya the existing power transmission lines are overstrained, particularly during peak hours when system voltages in parts of Nairobi, Coast, Western Kenya and Mt. Kenya is below acceptable levels. This leads to occasional load shedding measures despite the availability of generation capacity [11].

The first mitigation plans were set up through master plan under supervision of Kenya power and lighting company were three hundred distribution sub-stations were to be set up to address the growing power demand. This plan was later extended to be part of Vision 2030 [2].

Kenya Electricity Transmission Company (KETRACO) planned to erect new transmission lines to address the power transmission problem. The transmission lines were purposed to enhance adequacy, reliability and security of Electricity power supply in some counties of Kenya. The study reviewed that the existing transmission line lengths were as follows as on 2014/2015 master plan [8]: Table 1.

Table 1. *Length of transmission lines in Kenya (2014).*

VOLTAGE (kV)	LENGTH (km)
220	1,527
132	2,527
66	1,212
33	21,310
11	32,823
415/240 or 433/250	23,502
TOTAL	82,961

The sub-station capacity expanded from 3181 MVA in 2013/14 to 3612MVA in 2014/15.

The above researchers failed to analyze the voltage profile of the power lines and the power flow of the lines before erecting new power lines to address the power demand problem.

2.2. Voltage Stability

In recent past, the distribution networks in Kenya have witnessed large growth of terminated loads. This has been done in order to meet the high demand of power as the country works towards industrialization. This has made the power utility systems to operate close to voltage stability limits [9]. As the systems become more complex and heavily loaded, voltage instability becomes a serious problem which should be addressed immediately.

Voltage instability is a problem of stressed power lines, the main factor being failure of power system network to meet the reactive power demand [10]. The voltages which lie outside the normal operating range due to a disturbance, an increase in system load or change of voltage profile is an indicator of voltage instability [12].

3. Methodology

This section has discussed the Fast decoupled power flow method, methods of determining bus voltages and the simulation tools.

3.1. Proposed Methods

Maths works MATLAB/Simulink package is one of the widely used simulation software. This software allows the user to analyze complex power systems networks and visualization [13]. A simulation software in MATLAB environment allows power system to be simulated dynamically and allows a controller to be modelled with an aid of block diagrams.

Neplan power system software is another widely used power system analysis tool. This tool is used for planning, optimization and simulation of complex electricity networks. This software is extremely user friendly, has a graphical interface, with extensive libraries for the network elements, protection devices and control circuits which allows the user to perform studies very efficiently [14]. It is used in modelling transmission, distribution and generation power networks.

Powerworld simulator is a power system visualization, simulation and analysis tool. This tool is capable of solving problems in large power system networks. The software was used to analyze Juja-Rabai transmission power network with an aim of investigating the voltage network.

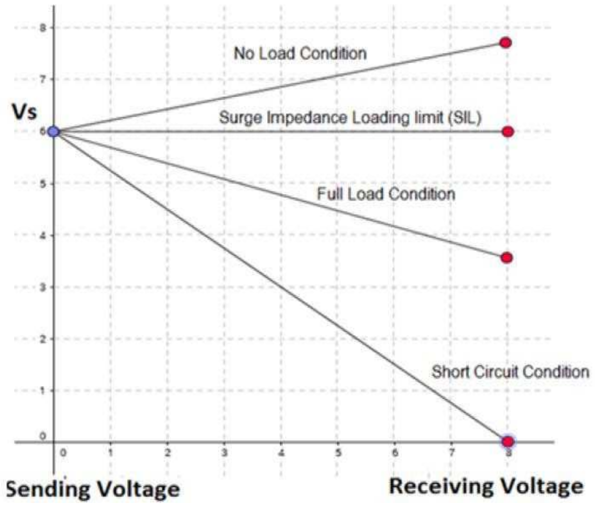

Figure 1. *Voltage profile under different condition.*

3.2. Mapping Method to Problem

The power flow simulation and bus voltages of the Juja-Rabai Power network will be analyzed. The study aimed at investigating when this transmission line is stable to accommodate termination of more distribution sub-stations to address the growing power demand. The study will be carried out using Powerworld simulator.

A transmission line is said to have a flat voltage profile if it's reactive power production is equal to reactive power consumption as shown in figure 1. The surge impedance loading is used in determining whether the power network is capable of handling extra load.

3.3. Problem Formulation

The initial step in this study was by formulation of the Y-matrix of Juja-Rabai transmission line.

$$Y_{ij} = \frac{1}{Z_{ij}} \quad (1)$$

The typical transmission line admittance equation is shown in appendices equation (8).

The computation of real and reactive power will be carried out as follows [15]:

$$P_i = |V_i{}^2||Y_{ii}| \cos \emptyset_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{\infty} ||V_i||V_k||Y_{ik}|| \cos (\emptyset_{ik} - \delta_i + \delta_k) \quad (2)$$

$$Q_i = \sum_{k=1}^{\infty} ||V_i||V_k||Y_{ik}|| \sin (\emptyset_{ik} - \delta_i + \delta_k) \quad (3)$$

Formation of Jacobian Matrix are as follows

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & 0 \\ 0 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V_4|| \end{bmatrix} \quad (4)$$

The Juja-Rabai transmission line elements J_1 and J_4 will be evaluated as shown in equations (9) and (10) in the appendices.

The changes in voltage magnitude and changes in phase angles were evaluated as captured in equations (14) and (15) in the appendices.

4. Results

4.1. Calculation Results

The transmission line change in phase angles were calculated by multipying the inverse of J_1 by changes in real power and results displayed as captured in equation (12) in the appendix.

$$\Delta\delta = J_1{}^{-1} * \Delta P \quad (5)$$

The initial bus phase angles were all zeros. The resultant bus phase angles of the calculated voltages using Fast Decoupled method were as captured in equation (13)

$$\delta^{(p+1)} = \delta^{(p)} + \Delta\delta^{(p)} \quad (6)$$

The changes in voltage levels are sensitive to variations in reactive power. The inverse of J_4 matrix was multiplied with changes in reactive power and the changes in bus voltages were as captured in equation (14) in the appendix.

$$\Delta|V| = J_4{}^{-1} * \Delta Q \quad (7)$$

The initial Bus voltage levels were all initially assumed to be 1.0 p.u apart from the slack Bus, which was taken to be 1.05 p.u. The changes in Bus voltage levels captured in equation (14) plus the assumed voltage levels resulted into new iterative bus values as captured in equation (15) in the appendix.

4.2. Simulation Results

A 29 Bus Juja-Rabai transmission line shown in Figure 3 was modelled in a Power world simulator software to study the voltage profile of the power line. The simulation results of table 2 and Fast Decoupled power flow voltage level results were plotted in a Cartesian plane and the results are as shown in Figure 2 below:

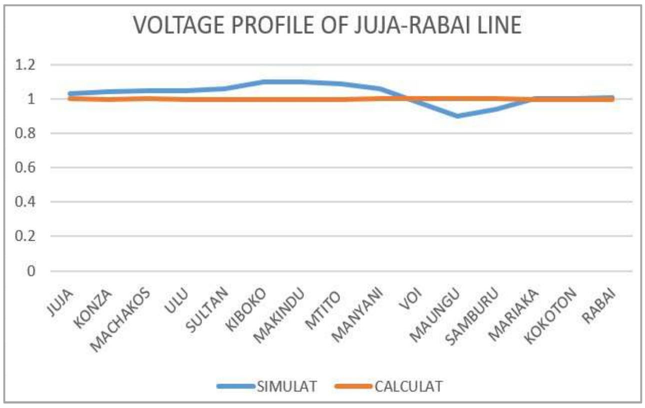

Figure 2. *Voltage profile.*

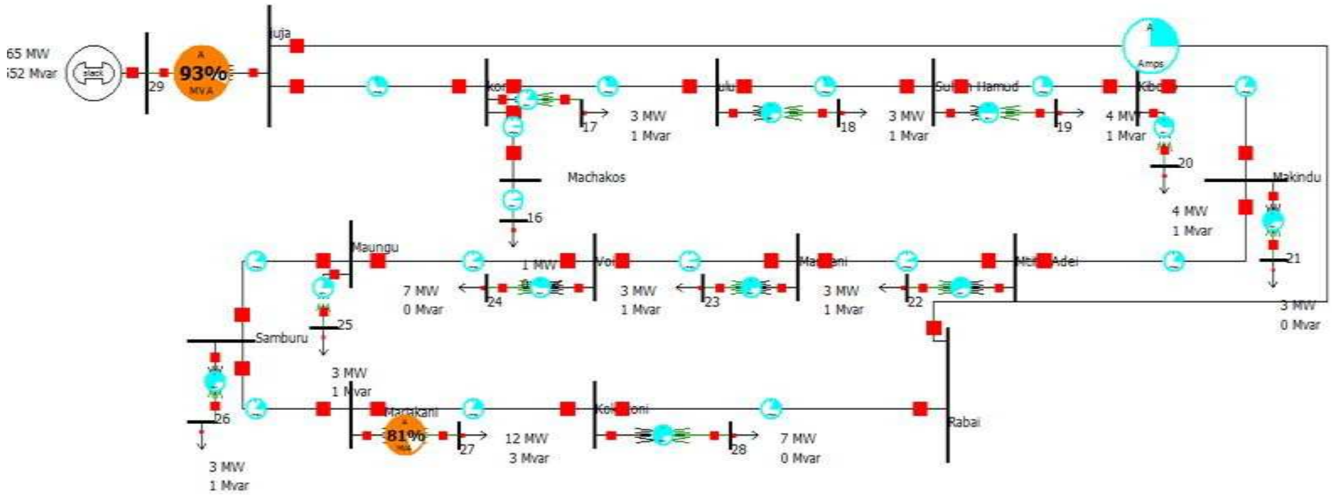

Figure 3. *Juja-rabai transmission line model.*

4.3. Voltage Profile

The Fast Decoupled voltage results and power world simulator results were used to plot the voltage profile of Juja-Rabai transmission line. The Bus voltage levels per unit values of each station were plotted against the corresponding towns and the results are as captured in Figure 2.

5. Discussion

This study involved the simulation of the 29-bus power network and the results were validated using Fast Decoupled load flow analysis method.

The simulation results and the calculated results had minimal variations. This was an indicator that, the Power world software results were accurate and reliable.

A voltage profile of 6% is the recommended voltage variation. A flat voltage profile occurs when there is a balance between the production and absorption of reactive power. The calculated values displayed a flat voltage profile and could be taken as the bench marking results to be used to draw results on the voltage profile of the network.

The busbar results in Kiboko sub-station and Makindu Sub-stations are highlighted red as an indicator that there are above the required maximum voltage limit by power utility companies. Bus 20 and 21 for power distribution has also been highlighted red. These high voltages are due to Ferranti effect and imbalance of reactive power. The effects of the four buses can be addressed by shunt and series reactive compensators. Thus the simulated Juja-Rabai network can be adjusted to a flat voltage profile.

The simulation results of Juja–Rabai 132kv transmission network displayed a network capable of accommodating more convention distribution substations to address the rising power demand in the country.

6. Conclusion

In this work, Decoupled load flow analysis and powerworld simulator were used to study the voltage profile of Juja-Rabai 132kV transmission line. The study revealed that the voltage profile of the network was violated from Voi substation to Rabai substation. Shunt compensator was terminated and the voltage profile was maintained at the recommended $\mp 5\%$ of the transmission voltage. The research work showed that more substations can be terminated on 132kv Juja-Rabai transmission line without voltage profile violation.

7. Mapping Method to Problem

The power flow simulation and bus voltages of the Juja-Rabai Power network were analyzed. The study aimed at investigating whether this transmission line is stable to accommodate termination of more distribution sub-stations to address the growing power demand. The study was carried out using Power world simulator.

Appendix

Table 2. *Powerworld voltage profile simulation results.*

Bus Number	SubstationName	Nominal voltage (kV)	P.u Voltage	Volts (kV)	Angle (Degrees)	Load (Mw)	Load (Mvar)
1	JUJA	132.00	1.03460	136.567	-2.82		
2	KONZA	132.00	1.04667	138.160	-3.02		
3	ULU	132.00	1.05120	138.756	-3.10		

Bus Number	SubstationName	Nominal voltage (kV)	P.u Voltage	Volts (kV)	Angle (Degrees)	Load (Mw)	Load (Mvar)
4	SULTAN HAMUD	132.00	1.08633	143.395	-3.61		
5	KIBOKO	132.00	1.10335	145.643	-3.99		
6	MAKINDU	132.00	1.10397	145.724	-4.04		
7	MTITO ADEI	132.00	1.09251	144.212	-4.11		
8	MANYANI	132.00	1.06075	140.023	-4.03		
9	VOI	132.00	0.98902	130.551	-3.92		
10	MAUNGU	132.00	0.90040	118.853	-3.54		
11	SAMBURU	132.00	0.94140	124.265	-3.57		
12	MARIAKANI	132.00	0.99575	131.439	-3.29		
13	KOKOTONI	132.00	1.00174	132.230	-3.23		
14	RABAI	132.00	1.000580	132.766	-3.16		
15	MACHAKOS	132.00	1.04756	138.278	-3.03		
16	16	33.00	1.04754	34.569	-3.05	1.00	0.03
17	17	33.00	1.05077	6.035	-3.17	3.30	1.00
18	18	6.60	1.08591	6.935	-3.69	3.50	1.00
19	19	33.00	1.10294	36.397	-4.07	3.70	1.00
20	20	33.00	1.10396	7.286	-4.11	3.10	0.00
21	21	6.60	1.09210	7.208	-4.16	2.70	1.00
22	22	6.60	1.06035	6.998	-4.10	3.10	1.00
23	23	6.60	0.98901	32.637	-4.09	6.50	0.00
24	24	33.00	0.89990	29.697	-3.64	3.00	1.00
25	25	33.00	0.94091	31.050	-3.66	3.20	1.00
26	26	33.00	0.99436	32.814	-3.60	11.20	3.00
27	27	33.00	1.00172	33.057	-3.41	11.70	3.00
28	28	33.00	1.00000	33.000	-3.00	6.50	0.00
29	29	33.00	1.00000	33.000	-3.00	6.50	0.00

$$Y_{Bmatrix}= \begin{bmatrix} Y11 & Y12 & Y13 & Y14 & - & - & Y112 & Y113 & Y114 & Y115 \\ Y21 & Y22 & Y23 & Y24 & - & - & Y212 & Y213 & Y214 & Y215 \\ Y31 & Y32 & Y33 & Y34 & - & - & Y312 & Y313 & Y314 & Y315 \\ Y41 & Y42 & Y43 & Y44 & - & - & Y412 & Y413 & Y414 & Y415 \\ Y51 & Y52 & Y53 & Y54 & - & - & Y512 & Y513 & Y514 & Y515 \\ Y61 & Y62 & Y63 & Y64 & - & - & Y612 & Y613 & Y614 & Y615 \\ Y71 & Y72 & Y73 & Y74 & - & - & Y712 & Y713 & Y714 & Y715 \\ -Y81 & Y82 & Y83 & Y84 & - & - & Y812 & Y813 & Y814 & Y815 \\ Y91 & Y92 & Y93 & Y94 & - & - & Y912 & Y813 & 914 & Y915 \\ Y101 & Y102 & Y103 & Y104 & - & - & Y1012 & Y1013 & Y1014 & Y1015 \\ Y111 & Y112 & Y113 & Y114 & - & - & Y1112 & Y1113 & Y1114 & Y1115 \\ Y121 & Y122 & Y123 & Y124 & - & - & Y1212 & Y1213 & Y1214 & Y1215 \\ Y131 & Y132 & Y133 & Y134 & - & - & Y1312 & Y1313 & Y1314 & Y1315 \\ Y141 & Y142 & Y143 & Y144 & - & - & Y1412 & Y1413 & Y1414 & Y1415 \\ 151 & 152 & Y153 & Y154 & - & - & Y1512 & Y1513 & Y1514 & Y1515 \end{bmatrix} \quad (8)$$

$$J_1 = \begin{bmatrix} \frac{dP2}{d\delta 2} & \frac{dP2}{d\delta 3} & \frac{dP2}{d\delta 4} & \frac{dP2}{d\delta 5} & \frac{dP2}{d\delta 6} & \frac{dP2}{d\delta 7} & \frac{dP2}{d\delta 8} & \frac{dP2}{d\delta 9} & \frac{dP2}{d\delta 10} & \frac{dP2}{d\delta 11} & \frac{dP2}{d\delta 12} & \frac{dP2}{d\delta 13} & \frac{dP2}{d\delta 14} \\ \frac{dP3}{d\delta 2} & \frac{dP3}{d\delta 3} & \frac{dP3}{d\delta 4} & \frac{dP3}{d\delta 5} & \frac{dP3}{d\delta 6} & \frac{dP3}{d\delta 7} & \frac{dP3}{d\delta 8} & \frac{dP3}{d\delta 9} & \frac{dP3}{d\delta 10} & \frac{dP3}{d\delta 11} & \frac{dP3}{d\delta 12} & \frac{dP3}{d\delta 13} & \frac{dP3}{d\delta 14} \\ \frac{dP4}{d\delta 2} & \frac{dP4}{d\delta 3} & \frac{dP4}{d\delta 4} & \frac{dP4}{d\delta 5} & \frac{dP4}{d\delta 6} & \frac{dP4}{d\delta 7} & \frac{dP4}{d\delta 8} & \frac{dP4}{d\delta 9} & \frac{dP4}{d\delta 10} & \frac{dP4}{d\delta 11} & \frac{dP4}{d\delta 12} & \frac{dP4}{d\delta 13} & \frac{dP4}{d\delta 14} \\ \frac{dP5}{d\delta 2} & \frac{dP5}{d\delta 3} & \frac{dP5}{d\delta 4} & \frac{dP5}{d\delta 5} & \frac{dP5}{d\delta 6} & \frac{dP5}{d\delta 7} & \frac{dP5}{d\delta 8} & \frac{dP5}{d\delta 9} & \frac{dP5}{d\delta 10} & \frac{dP5}{d\delta 11} & \frac{dP5}{d\delta 12} & \frac{dP5}{d\delta 13} & \frac{dP5}{d\delta 14} \\ \frac{dP6}{d\delta 2} & \frac{dP6}{d\delta 3} & \frac{dP6}{d\delta 4} & \frac{dP6}{d\delta 5} & \frac{dP6}{d\delta 6} & \frac{dP6}{d\delta 7} & \frac{dP6}{d\delta 8} & \frac{dP6}{d\delta 9} & \frac{dP6}{d\delta 10} & \frac{dP6}{d\delta 11} & \frac{dP6}{d\delta 12} & \frac{dP6}{d\delta 13} & \frac{dP6}{d\delta 14} \\ \frac{dP7}{d\delta 2} & \frac{dP7}{d\delta 3} & \frac{dP7}{d\delta 4} & \frac{dP7}{d\delta 5} & \frac{dP7}{d\delta 6} & \frac{dP7}{d\delta 7} & \frac{dP7}{d\delta 8} & \frac{dP7}{d\delta 9} & \frac{dP7}{d\delta 10} & \frac{dP7}{d\delta 11} & \frac{dP7}{d\delta 12} & \frac{dP7}{d\delta 13} & \frac{dP7}{d\delta 14} \\ \frac{dP8}{d\delta 2} & \frac{dP8}{d\delta 3} & \frac{dP8}{d\delta 4} & \frac{dP8}{d\delta 5} & \frac{dP8}{d\delta 6} & \frac{dP8}{d\delta 7} & \frac{dP8}{d\delta 8} & \frac{dP8}{d\delta 9} & \frac{dP8}{d\delta 10} & \frac{dP8}{d\delta 11} & \frac{dP8}{d\delta 12} & \frac{dP8}{d\delta 13} & \frac{dP8}{d\delta 14} \\ \frac{dP9}{d\delta 2} & \frac{dP9}{d\delta 3} & \frac{dP9}{d\delta 4} & \frac{dP9}{d\delta 5} & \frac{dP9}{d\delta 6} & \frac{dP9}{d\delta 7} & \frac{dP9}{d\delta 8} & \frac{dP9}{d\delta 9} & \frac{dP9}{d\delta 10} & \frac{dP9}{d\delta 11} & \frac{dP9}{d\delta 12} & \frac{dP9}{d\delta 13} & \frac{dP9}{d\delta 14} \\ \frac{dP10}{d\delta 2} & \frac{dP10}{d\delta 3} & \frac{dP10}{d\delta 4} & \frac{dP10}{d\delta 5} & \frac{dP10}{d\delta 6} & \frac{dP10}{d\delta 7} & \frac{dP10}{d\delta 8} & \frac{dP10}{d\delta 9} & \frac{dP10}{d\delta 10} & \frac{dP10}{d\delta 11} & \frac{dP10}{d\delta 12} & \frac{dP10}{d\delta 13} & \frac{dP10}{d\delta 14} \\ \frac{dP11}{d\delta 2} & \frac{dP11}{d\delta 3} & \frac{dP11}{d\delta 4} & \frac{dP11}{d\delta 5} & \frac{dP11}{d\delta 6} & \frac{dP11}{d\delta 7} & \frac{dP11}{d\delta 8} & \frac{dP11}{d\delta 9} & \frac{dP11}{d\delta 10} & \frac{dP11}{d\delta 11} & \frac{dP11}{d\delta 12} & \frac{dP11}{d\delta 13} & \frac{dP11}{d\delta 14} \\ \frac{dP12}{d\delta 2} & \frac{dP12}{d\delta 3} & \frac{dP12}{d\delta 4} & \frac{dP12}{d\delta 5} & \frac{dP12}{d\delta 6} & \frac{dP12}{d\delta 7} & \frac{dP12}{d\delta 8} & \frac{dP12}{d\delta 9} & \frac{dP12}{d\delta 10} & \frac{dP12}{d\delta 11} & \frac{dP12}{d\delta 12} & \frac{dP12}{d\delta 13} & \frac{dP12}{d\delta 14} \\ \frac{dP13}{d\delta 2} & \frac{dP13}{d\delta 3} & \frac{dP13}{d\delta 4} & \frac{dP13}{d\delta 5} & \frac{dP13}{d\delta 6} & \frac{dP13}{d\delta 7} & \frac{dP13}{d\delta 8} & \frac{dP13}{d\delta 9} & \frac{dP13}{d\delta 10} & \frac{dP13}{d\delta 11} & \frac{dP13}{d\delta 12} & \frac{dP13}{d\delta 13} & \frac{dP13}{d\delta 14} \\ \frac{dP14}{d\delta 2} & \frac{dP14}{d\delta 3} & \frac{dP14}{d\delta 4} & \frac{dP14}{d\delta 5} & \frac{dP14}{d\delta 6} & \frac{dP14}{d\delta 7} & \frac{dP14}{d\delta 8} & \frac{dP14}{d\delta 9} & \frac{dP14}{d\delta 10} & \frac{dP14}{d\delta 11} & \frac{dP14}{d\delta 12} & \frac{dP14}{d\delta 13} & \frac{dP14}{d\delta 14} \end{bmatrix} \tag{9}$$

$$J_4 = \begin{bmatrix} \frac{dP2}{d\delta 2} & \frac{dP2}{d\delta 3} & \frac{dP2}{d\delta 4} & \frac{dP2}{d\delta 5} & \frac{dP2}{d\delta 6} & \frac{dP2}{d\delta 7} & \frac{dP2}{d\delta 8} & \frac{dP2}{d\delta 9} & \frac{dP2}{d\delta 10} & \frac{dP2}{d\delta 11} & \frac{dP2}{d\delta 12} & \frac{dP2}{d\delta 13} & \frac{dP2}{d\delta 14} \\ \frac{dP3}{d\delta 2} & \frac{dP3}{d\delta 3} & \frac{dP3}{d\delta 4} & \frac{dP3}{d\delta 5} & \frac{dP3}{d\delta 6} & \frac{dP3}{d\delta 7} & \frac{dP3}{d\delta 8} & \frac{dP3}{d\delta 9} & \frac{dP3}{d\delta 10} & \frac{dP3}{d\delta 11} & \frac{dP3}{d\delta 12} & \frac{dP3}{d\delta 13} & \frac{dP3}{d\delta 14} \\ \frac{dP4}{d\delta 2} & \frac{dP4}{d\delta 3} & \frac{dP4}{d\delta 4} & \frac{dP4}{d\delta 5} & \frac{dP4}{d\delta 6} & \frac{dP4}{d\delta 7} & \frac{dP4}{d\delta 8} & \frac{dP4}{d\delta 9} & \frac{dP4}{d\delta 10} & \frac{dP4}{d\delta 11} & \frac{dP4}{d\delta 12} & \frac{dP4}{d\delta 13} & \frac{dP4}{d\delta 14} \\ \frac{dP5}{d\delta 2} & \frac{dP5}{d\delta 3} & \frac{dP5}{d\delta 4} & \frac{dP5}{d\delta 5} & \frac{dP5}{d\delta 6} & \frac{dP5}{d\delta 7} & \frac{dP5}{d\delta 8} & \frac{dP5}{d\delta 9} & \frac{dP5}{d\delta 10} & \frac{dP5}{d\delta 11} & \frac{dP5}{d\delta 12} & \frac{dP5}{d\delta 13} & \frac{dP5}{d\delta 14} \\ \frac{dP6}{d\delta 2} & \frac{dP6}{d\delta 3} & \frac{dP6}{d\delta 4} & \frac{dP6}{d\delta 5} & \frac{dP6}{d\delta 6} & \frac{dP6}{d\delta 7} & \frac{dP6}{d\delta 8} & \frac{dP6}{d\delta 9} & \frac{dP6}{d\delta 10} & \frac{dP6}{d\delta 11} & \frac{dP6}{d\delta 12} & \frac{dP6}{d\delta 13} & \frac{dP6}{d\delta 14} \\ \frac{dP7}{d\delta 2} & \frac{dP7}{d\delta 3} & \frac{dP7}{d\delta 4} & \frac{dP7}{d\delta 5} & \frac{dP7}{d\delta 6} & \frac{dP7}{d\delta 7} & \frac{dP7}{d\delta 8} & \frac{dP7}{d\delta 9} & \frac{dP7}{d\delta 10} & \frac{dP7}{d\delta 11} & \frac{dP7}{d\delta 12} & \frac{dP7}{d\delta 13} & \frac{dP7}{d\delta 14} \\ \frac{dP8}{d\delta 2} & \frac{dP8}{d\delta 3} & \frac{dP8}{d\delta 4} & \frac{dP8}{d\delta 5} & \frac{dP8}{d\delta 6} & \frac{dP8}{d\delta 7} & \frac{dP8}{d\delta 8} & \frac{dP8}{d\delta 9} & \frac{dP8}{d\delta 10} & \frac{dP8}{d\delta 11} & \frac{dP8}{d\delta 12} & \frac{dP8}{d\delta 13} & \frac{dP8}{d\delta 14} \\ \frac{dP9}{d\delta 2} & \frac{dP9}{d\delta 3} & \frac{dP9}{d\delta 4} & \frac{dP9}{d\delta 5} & \frac{dP9}{d\delta 6} & \frac{dP9}{d\delta 7} & \frac{dP9}{d\delta 8} & \frac{dP9}{d\delta 9} & \frac{dP9}{d\delta 10} & \frac{dP9}{d\delta 11} & \frac{dP9}{d\delta 12} & \frac{dP9}{d\delta 13} & \frac{dP9}{d\delta 14} \\ \frac{dP10}{d\delta 2} & \frac{dP10}{d\delta 3} & \frac{dP10}{d\delta 4} & \frac{dP10}{d\delta 5} & \frac{dP10}{d\delta 6} & \frac{dP10}{d\delta 7} & \frac{dP10}{d\delta 8} & \frac{dP10}{d\delta 9} & \frac{dP10}{d\delta 10} & \frac{dP10}{d\delta 11} & \frac{dP10}{d\delta 12} & \frac{dP10}{d\delta 13} & \frac{dP10}{d\delta 14} \\ \frac{dP11}{d\delta 2} & \frac{dP11}{d\delta 3} & \frac{dP11}{d\delta 4} & \frac{dP11}{d\delta 5} & \frac{dP11}{d\delta 6} & \frac{dP11}{d\delta 7} & \frac{dP11}{d\delta 8} & \frac{dP11}{d\delta 9} & \frac{dP11}{d\delta 10} & \frac{dP11}{d\delta 11} & \frac{dP11}{d\delta 12} & \frac{dP11}{d\delta 13} & \frac{dP11}{d\delta 14} \\ \frac{dP12}{d\delta 2} & \frac{dP12}{d\delta 3} & \frac{dP12}{d\delta 4} & \frac{dP12}{d\delta 5} & \frac{dP12}{d\delta 6} & \frac{dP12}{d\delta 7} & \frac{dP12}{d\delta 8} & \frac{dP12}{d\delta 9} & \frac{dP12}{d\delta 10} & \frac{dP12}{d\delta 11} & \frac{dP12}{d\delta 12} & \frac{dP12}{d\delta 13} & \frac{dP12}{d\delta 14} \\ \frac{dP13}{d\delta 2} & \frac{dP13}{d\delta 3} & \frac{dP13}{d\delta 4} & \frac{dP13}{d\delta 5} & \frac{dP13}{d\delta 6} & \frac{dP13}{d\delta 7} & \frac{dP13}{d\delta 8} & \frac{dP13}{d\delta 9} & \frac{dP13}{d\delta 10} & \frac{dP13}{d\delta 11} & \frac{dP13}{d\delta 12} & \frac{dP13}{d\delta 13} & \frac{dP13}{d\delta 14} \\ \frac{dP14}{d\delta 2} & \frac{dP14}{d\delta 3} & \frac{dP14}{d\delta 4} & \frac{dP14}{d\delta 5} & \frac{dP14}{d\delta 6} & \frac{dP14}{d\delta 7} & \frac{dP14}{d\delta 8} & \frac{dP14}{d\delta 9} & \frac{dP14}{d\delta 10} & \frac{dP14}{d\delta 11} & \frac{dP14}{d\delta 12} & \frac{dP14}{d\delta 13} & \frac{dP14}{d\delta 14} \end{bmatrix} \tag{10}$$

$$
\begin{bmatrix}
\frac{\delta P2}{\delta\delta 2} & \frac{\delta P2}{\delta\delta 3} & \frac{\delta P2}{\delta\delta 4} & - & - & \frac{\delta P2}{\delta\delta 10} & \frac{\delta P2}{\delta\delta 11} & \frac{\delta P2}{\delta\delta 12} & \frac{\delta P2}{\delta\delta 13} & \frac{\delta P2}{\delta\delta 14} \\
\frac{\delta P3}{\delta\delta 2} & \frac{\delta P3}{\delta\delta 3} & \frac{\delta P3}{\delta\delta 4} & - & - & \frac{\delta P3}{\delta\delta 10} & \frac{\delta P3}{\delta\delta 11} & \frac{\delta P3}{\delta\delta 12} & \frac{\delta P3}{\delta 13} & \frac{\delta P3}{\delta\delta 14} \\
\frac{\delta P4}{\delta\delta 2} & \frac{\delta P4}{\delta\delta 3} & \frac{\delta P4}{\delta\delta 4} & - & - & \frac{\delta P4}{\delta\delta 10} & \frac{\delta P4}{\delta\delta 11} & \frac{\delta P4}{\delta\delta 12} & \frac{\delta P4}{\delta\delta 13} & \frac{\delta P4}{\delta\delta 14} \\
\frac{\delta P5}{\delta\delta 2} & \frac{\delta P5}{\delta\delta 3} & \frac{\delta P5}{\delta\delta 4} & - & - & \frac{\delta P5}{\delta\delta 10} & \frac{\delta P5}{\delta\delta 11} & \frac{\delta P5}{\delta\delta 12} & \frac{\delta P5}{\delta\delta 13} & \frac{\delta P5}{\delta\delta 14} \\
\frac{\delta P6}{\delta\delta 2} & \frac{\delta P6}{\delta\delta 3} & \frac{\delta P6}{\delta\delta 4} & - & - & \frac{\delta P6}{\delta\delta 10} & \frac{\delta P6}{\delta\delta 11} & \frac{\delta P6}{\delta\delta 12} & \frac{\delta P6}{\delta\delta 13} & \frac{\delta P6}{\delta\delta 14} \\
\frac{\delta P7}{\delta\delta 2} & \frac{\delta P7}{\delta\delta 3} & \frac{\delta P7}{\delta\delta 4} & - & - & \frac{\delta P7}{\delta\delta 10} & \frac{\delta P7}{\delta\delta 11} & \frac{\delta P7}{\delta\delta 12} & \frac{\delta P7}{\delta\delta 13} & \frac{\delta P7}{\delta\delta 14} \\
\frac{\delta P8}{\delta\delta 2} & \frac{\delta P8}{\delta\delta 3} & \frac{\delta P8}{\delta\delta 4} & - & - & \frac{\delta P8}{\delta\delta 10} & \frac{\delta P8}{d\delta 11} & \frac{\delta P8}{\delta\delta 12} & \frac{\delta P8}{\delta\delta 13} & \frac{\delta P8}{\delta\delta 14} \\
\frac{\delta P9}{\delta\delta 2} & \frac{\delta P9}{\delta\delta 3} & \frac{\delta P9}{\delta\delta 4} & - & - & \frac{\delta P9}{\delta\delta 10} & \frac{\delta P9}{\delta\delta 11} & \frac{\delta P9}{\delta\delta 12} & \frac{\delta P9}{\delta\delta 13} & \frac{\delta P9}{d\delta 14} \\
\frac{\delta P10}{\delta\delta 2} & \frac{\delta P10}{\delta\delta 3} & \frac{\delta P10}{\delta\delta 4} & - & - & \frac{\delta P10}{\delta\delta 10} & \frac{\delta P10}{\delta\delta 11} & \frac{\delta P10}{\delta\delta 12} & \frac{\delta P10}{\delta\delta 13} & \frac{\delta P10}{\delta\delta 14} \\
\frac{\delta P11}{\delta\delta 2} & \frac{\delta P11}{\delta\delta 3} & \frac{\delta P11}{\delta\delta 4} & - & - & \frac{\delta P11}{\delta\delta 10} & \frac{\delta P11}{\delta\delta 11} & \frac{\delta P11}{\delta\delta 12} & \frac{\delta P11}{\delta\delta 13} & \frac{\delta P11}{\delta\delta 14} \\
\frac{\delta P12}{\delta\delta 2} & \frac{\delta P12}{\delta\delta 3} & \frac{\delta P12}{\delta\delta 4} & - & - & \frac{\delta P12}{\delta\delta 10} & \frac{\delta P12}{\delta\delta 11} & \frac{\delta P12}{\delta\delta 12} & \frac{\delta P12}{\delta\delta 13} & \frac{\delta P12}{\delta\delta 14} \\
\frac{\delta P13}{\delta\delta 2} & \frac{\delta P13}{\delta\delta 3} & \frac{\delta P13}{\delta\delta 4} & - & - & \frac{\delta P13}{\delta\delta 10} & \frac{\delta P13}{\delta\delta 11} & \frac{\delta P13}{\delta\delta 12} & \frac{\delta P13}{\delta\delta 13} & \frac{\delta P13}{\delta\delta 14} \\
\frac{\delta P14}{\delta\delta 2} & \frac{\delta P14}{\delta\delta 3} & \frac{\delta P14}{\delta\delta 4} & - & - & \frac{\delta P14}{\delta\delta 10} & \frac{\delta P14}{\delta\delta 11} & \frac{\delta P14}{\delta\delta 12} & \frac{\delta P14}{\delta\delta 13} & \frac{\delta P14}{\delta\delta 14} \\
\frac{\delta Q2}{\delta|v2|} & \frac{\delta Q2}{\delta|v3|} & \frac{\delta Q2}{\delta|v4|} & - & - & \frac{\delta Q2}{\delta|v10|} & \frac{\delta Q2}{\delta|v11|} & \frac{\delta Q2}{\delta|v12|} & \frac{\delta Q2}{\delta|v13|} & \frac{\delta Q2}{\delta|v14|} \\
\frac{\delta Q3}{\delta|v2|} & \frac{\delta Q3}{\delta|v3|} & \frac{\delta Q3}{\delta|v4|} & - & - & \frac{\delta Q3}{\delta|v10|} & \frac{\delta Q3}{\delta|v11|} & \frac{\delta Q3}{\delta|v12|} & \frac{\delta Q3}{\delta|v13|} & \frac{\delta Q3}{\delta|v14|} \\
\frac{\delta Q4}{\delta|v2|} & \frac{\delta Q4}{\delta|v3|} & \frac{\delta Q4}{\delta|v4|} & - & - & \frac{\delta Q4}{\delta|v10|} & \frac{\delta Q4}{\delta|v11|} & \frac{\delta Q4}{\delta|v12|} & \frac{\delta Q4}{\delta|v13|} & \frac{\delta Q4}{\delta|v14|} \\
\frac{\delta Q5}{\delta|v2|} & \frac{\delta Q5}{\delta|v3|} & \frac{\delta Q5}{\delta|v4|} & - & - & \frac{\delta Q5}{\delta|v10|} & \frac{\delta Q5}{\delta|v11|} & \frac{\delta Q5}{\delta|v12|} & \frac{\delta Q5}{\delta|v13|} & \frac{\delta Q5}{\delta|v14|} \\
\frac{\delta Q6}{\delta|v2|} & \frac{\delta Q6}{\delta|v3|} & \frac{\delta Q6}{\delta|v4|} & - & - & \frac{\delta Q6}{\delta|v10|} & \frac{\delta Q6}{\delta|v11|} & \frac{\delta Q6}{\delta|v12|} & \frac{\delta Q6}{\delta|v13|} & \frac{\delta Q6}{\delta|v14|} \\
\frac{\delta Q7}{\delta|v2|} & \frac{\delta Q7}{\delta|v3|} & \frac{\delta Q7}{\delta|v4|} & - & - & \frac{\delta Q7}{\delta|v10|} & \frac{\delta Q7}{\delta|v11|} & \frac{\delta Q7}{\delta|v12|} & \frac{\delta Q7}{\delta|v13|} & \frac{\delta Q7}{\delta|v14|} \\
\frac{\delta Q8}{\delta|v2|} & \frac{\delta Q8}{\delta|v3|} & \frac{\delta Q8}{\delta|v4|} & - & - & \frac{\delta Q8}{\delta|v10|} & \frac{\delta Q8}{\delta|v11|} & \frac{\delta Q8}{\delta|v12|} & \frac{\delta Q8}{\delta|v13|} & \frac{\delta Q8}{\delta|v14|} \\
\frac{\delta Q9}{\delta|v2|} & \frac{\delta Q9}{\delta|v3|} & \frac{\delta Q9}{\delta|v4|} & - & - & \frac{\delta Q9}{\delta|v10|} & \frac{\delta Q9}{\delta|v11|} & \frac{\delta Q}{\delta|v12|} & \frac{\delta Q9}{\delta|v13|} & \frac{\delta Q9}{\delta|v14|} \\
\frac{\delta Q10}{\delta|v2|} & \frac{\delta Q10}{\delta|v3|} & \frac{\delta Q10}{\delta|v4|} & - & - & \frac{\delta Q10}{\delta|v10|} & \frac{\delta Q10}{\delta|v11|} & \frac{\delta Q10}{\delta|v12|} & \frac{\delta Q10}{\delta|v13|} & \frac{\delta Q10}{\delta|v14|} \\
\frac{\delta Q11}{\delta|v2|} & \frac{\delta Q11}{\delta|v3|} & \frac{\delta Q11}{\delta|v4|} & - & - & \frac{\delta Q11}{\delta|v10|} & \frac{\delta Q11}{\delta|v11|} & \frac{\delta Q11}{\delta|v12|} & \frac{\delta Q11}{\delta|v13|} & \frac{\delta Q11}{\delta|v14|} \\
\frac{\delta Q12}{\delta|v2|} & \frac{\delta Q12}{\delta|v3|} & \frac{\delta Q12}{\delta|v4|} & - & - & \frac{\delta Q12}{\delta|v10|} & \frac{\delta Q12}{\delta|v11|} & \frac{\delta Q12}{\delta|v12|} & \frac{\delta Q12}{\delta|v13|} & \frac{\delta Q112}{\delta|v14|} \\
\frac{\delta Q13}{\delta\|v2|} & \frac{\delta Q13}{\delta|v3|} & \frac{\delta Q13}{\delta|v4|} & - & - & \frac{\delta Q13}{\delta|v10|} & \frac{\delta Q13}{\delta|v11|} & \frac{\delta Q13}{\delta|v12|} & \frac{\delta Q13}{\delta|v13} & \frac{\delta Q13}{\delta|v14|} \\
\frac{\delta Q14}{\delta|v2|} & \frac{\delta Q14}{\delta|v3|} & \frac{\delta Q14}{\delta|v4|} & - & - & \frac{\delta Q14}{\delta|va1|} & \frac{\delta Q14}{\delta|v11|} & \frac{\delta Q14}{\delta|v12|} & \frac{\delta Q14}{\delta|v13|} & \frac{\delta Q14}{\delta|v14|}
\end{bmatrix}
\tag{11}
$$

$$\begin{bmatrix} \Delta\delta 2 \\ \Delta\delta 3 \\ \Delta\delta 4 \\ \Delta\delta 5 \\ \Delta\delta 6 \\ \Delta\delta 7 \\ \Delta\delta 8 \\ \Delta\delta 9 \\ \Delta\delta 10 \\ \Delta\delta 11 \\ \Delta\delta 12 \\ \Delta\delta 13 \\ \Delta\delta 14 \end{bmatrix} = \begin{bmatrix} 0.0306 \\ 0.0306 \\ 0.000405 \\ -0.000257 \\ -0.03814 \\ 0.00009316 \\ 0.043407 \\ 0.001676 \\ -0.004703 \\ -0.019726 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \quad (12)$$

$$\begin{bmatrix} \delta 2 \\ \delta 3 \\ \delta 4 \\ \delta 5 \\ \delta 6 \\ \delta 7 \\ \delta 8 \\ \delta 9 \\ \delta 10 \\ \delta 11 \\ \delta 12 \\ \delta 13 \\ \delta 14 \end{bmatrix} = \begin{bmatrix} 0.0306 \\ 0.0306 \\ 0.000405 \\ -0.000257 \\ -0.03814 \\ 0.00009316 \\ 0.043407 \\ 0.001676 \\ -0.004703 \\ -0.019726 \\ 0.00 \\ 0.00 \\ 0.00 \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} \Delta|V2| \\ \Delta|V3| \\ \Delta|V4| \\ \Delta|V5| \\ \Delta|V6| \\ \Delta|V7| \\ \Delta|V8| \\ \Delta|V9| \\ \Delta|V10| \\ \Delta|V11| \\ \Delta|V12| \\ \Delta|V13| \\ \Delta|V14| \end{bmatrix} = \begin{bmatrix} -0.00496 \\ -0.005 \\ =0.005 \\ -0.005 \\ -0.0027 \\ -0.00225 \\ 0.0007 \\ 0.00085 \\ -0.0002 \\ -.000365 \\ -0.00066 \\ -0.000977 \\ 0.000457 \end{bmatrix} \quad (14)$$

$$\begin{bmatrix} |V2| \\ |V3| \\ |V4| \\ |V5| \\ |V6| \\ |V7| \\ |V8| \\ |V9| \\ |V10| \\ |V11| \\ |V12| \\ |V13| \\ |V14| \end{bmatrix} = \begin{bmatrix} 0.99504 \\ 0.995 \\ 0.9949 \\ 0.9949 \\ 0.9973 \\ 099775 \\ 0.9993 \\ 0.00085 \\ 1.00085 \\ 100002 \\ 0.999635 \\ 0.99934 \\ 0.999023 \end{bmatrix} \quad (15)$$

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