Static Voltage Stability Assessment Considering the Power System Contingencies using Continuation Power Flow Method

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***Abstract*—**According to the increasing utilization in power system, the transmission lines and power plants often operate in stability boundary and system probably lose its stable condition by over loading or occurring disturbance. According to the reasons that are mentioned, the prediction and recognition of voltage instability in power system has particular importance and it makes the network security stronger.This paper, by considering of power system contingencies based on the effects of them on Mega Watt Margin (MWM) and maximum loading point is focused in order to analyse the static voltage stability using continuation power flow method. The study has been carried out on IEEE 14-Bus Test System using Matlab and Psat softwares and results are presented.

***Keywords*—**Contingency, Continuation Power Flow, Static Voltage Stability, Voltage Collapse**.**

I. INTRODUCTION

ELECTRICITY consumption increasing affects power system complexity and system works in near instability limit attention to high consumption. When a crisis, regardless its reason, occurs in a power system, voltage drops in a specified bus intensively until leads all the system to instability that yields to voltage collapse. There are two major problems analyzing static voltage stability :

i) Maximum loading point (MLP)

ii) Mega Watt Margin (MWM).

For an ideal condition, when system does not experience an event and all components work correctly in system, system can provide maximum loading point and so its corresponding maximum mega watt margin. So to analyze how much power system is utilized safe, it needs to simulate possible contingencies for power system and network performance to be considered for each event. surveying contingencies to analysis static voltage stability, contingencies ranking are among necessary aspects of voltage safety. Ranking all possible contingencies based on their impact on the system voltage profile will help the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse [1]. In [2], surveying possible contingencies with ranking according to line FVSI indicator is carried out. The method of ranking the possible contingency based on right eigenvector and branch parameter specially in [3] is given. Appearing the artificial intelligence, possible contingency ranking is done based on neural networks [4]-[6], fuzzy logic [7], [8] and genetic algorithm [9]. In this paper applying continuation power flow (CPF) that is based on reformulation of load flow equations applying a continuum parameter, calculating MLP and its correspomding mega watt margin decrease percent in each contingency, we set to ranking of possible contingencies based on the severity of their effect on static voltage collapse.

The necessary and preliminary parts of background material on static voltage stability and surveying possible contingencies are described in Section II, and the proposed contingency ranking method and its corresponding flowchart are provided in Section III. The results of ranking contingencies for the IEEE 14-Bus system are included in Section IV.

II. STATIC VOLTAGE STABILITY AND SURVEYING POSSIBLE CONTINGENCIES

A power system could utilize in safe manner when the occurrence of each possible contingency can not to exit system from normal work. Power system works in abnormal manner that variables exit from their allowed limit or the equilibrium between generation and consumption of energy spoils. Each event in power system would change the configuration of network that itself results in contraction of $V-\lambda$ curve and so decrease of MLP and its corresponding MWM. So for an ideal conditions when system do not experience a contingency and all components work correctly, system can prepare MLP and Maximum Mega Watt Margin (MMWM). In a power system we encounter with too many contingencies that may results in overload in some of lines and/or bus voltages deviation from their allowed limit so that the position of the weakest bus may change.

Figure. 1 shows $V-\lambda$ curve with MLP and Megawatt margin in appearing contingencies. The system may be operating at a stable equilibrium point but a contingency at maximum loading point may land unstable region or where there are no solution to the system equations. The main reason

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for low voltage profile for some contingency and therefore smaller MWM is the insufficient reactive power in the vicinity of the low voltage buses [10]-[12]. There are some severity contingencies with very low loading that are a small function of maximum loading, while for some other contingencies, the loading margin is near to its maximum. Contingencies ranking that are considered as necessary aspects of static voltage stability analysis, we can identify more critical contingencies to create preventive and improving strategies to avoid static voltage instability that occurs because of this sever contingency.

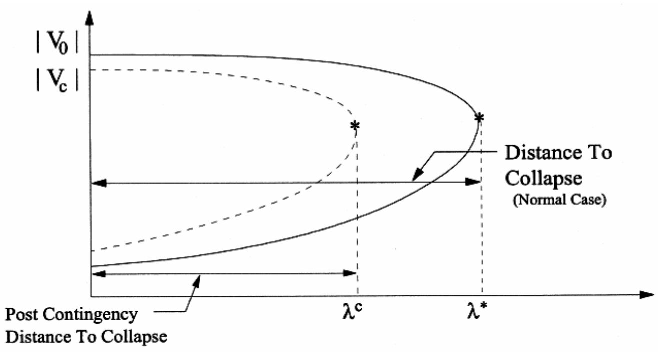

Fig. 1 Voltage Collapse Point at Pre-Contingency and Post-Contingency.

III. Contingencies Ranking with Continuation Power Flow Method

As discussed in pervious section, contingencies ranking are considered as major aspects in surveying contingencies in power system. Processing to contingencies ranking, first we calculate the variables of power system using an analytical method for each event and then the severity of effect in each event are calculated based on an performance indicator that is function of these variables. Figure. 2 shows the flowchart of ranking for contingencies. Attention to figure, appearing each contingency (like line outages and/or generation unit outages), the MLP and its corresponding MWM decrease percent would be calculated by continuation power flow method. Arranging MLP as ascending and its corresponding MWM decrease percent as descending, contingencies with lower MLP and higher MWM decrease percent set in higher ranks.MMWM and MWM calculate for system as :

$$\text{MMWM} = P_{i\max} - P_{base} \quad (1)$$

$$\text{MWM} = P_{i+1\max} - P_{base} \quad (2)$$

Where $P_{\max}$ is maximum load active power corresponding with MLP and P_{base} is base load active power. The MWM decrease percent is also calculated based on this :

$$\text{MWM decrease percent} = 100 \times [1-(\frac{MWM}{MMWM})] \quad (3)$$

In power systems, the numbers of contingencies is dependent the number the elements exposed to failure in the system.

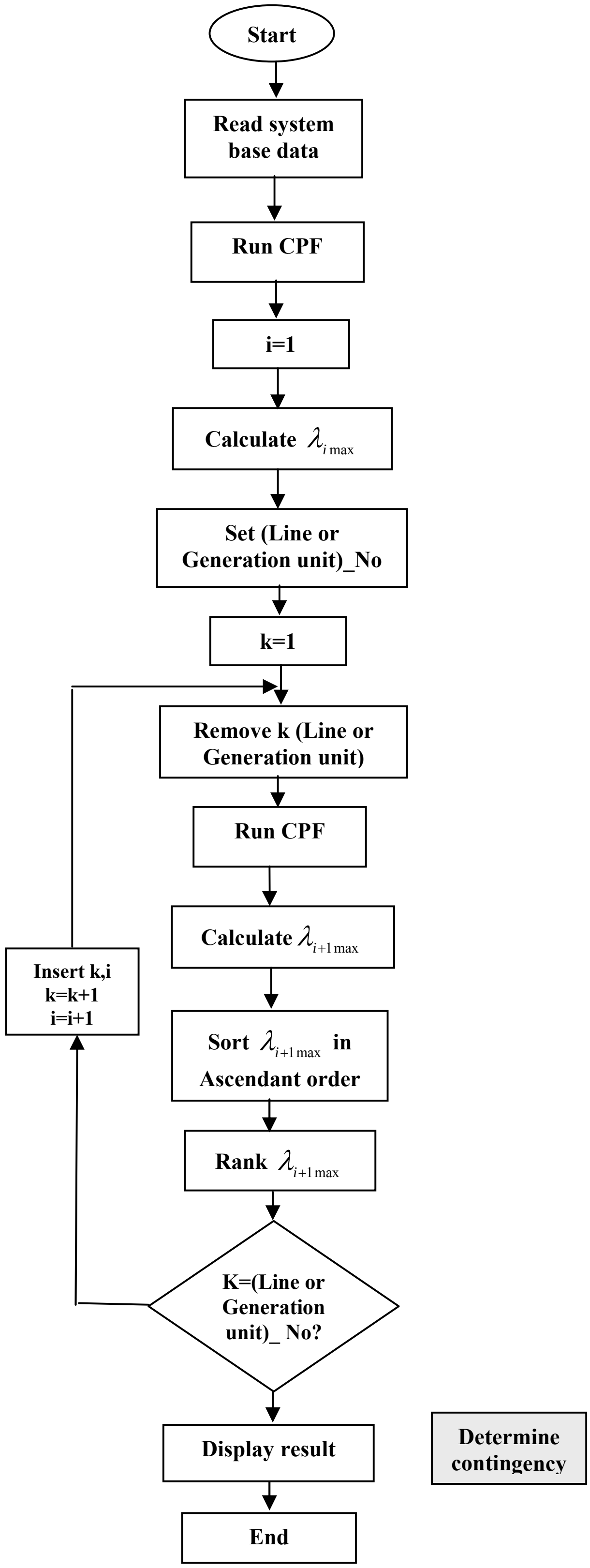

Fig. 2 The flowchart for contingencies ranking of first level.

For event numbers of L level with NC_L : L=0,1,2,…,N we have [1]:

$$NC_L = \frac{N!}{L!(N-L)!} \quad (4)$$

The zero level contingency, NC_0, means no element in the system is subject to failure.

Contingency of first level, NC_1 is equal with unique element numbers exposed to failure In power system the total number of all possible contingencies is extensive, so usually the first level or sometimes the second level contingencies are considered The total number of zero, first and second level contingencies, $NC_{0,2}$ is given in (5).

$$NC_{o,2} = \sum_{L=0}^{2} NC_L = 1 + N + \frac{1}{2}(N)(N-1) \quad (5)$$

In this paper contingencies of zero level and first level are considered so we have:

$$NC_{0,1} = \sum_{L=0}^{1} NC_L = 1+\text{N} \quad (6)$$

IV. UNDER STUDY NETWORK

Our test system is a IEEE 14-bus system. Stimulated diagram of System with 14 bus is drawn in Psat software in figure. 3. This system has 5 generation units that bus 1 is slack bus. Also it has 16 transmission lines, 4 transformators and 11 load buses.

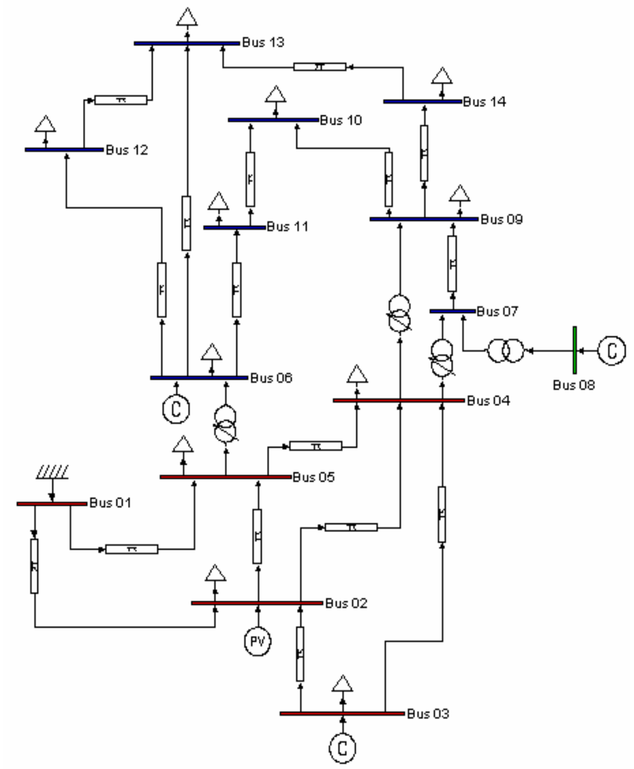

Fig. 3 The IEEE 14-bus test system.

In this system generation unit are modeled as standard PV buses and loads are represented as constant PQ loads. The P and Q load powers are not voltage dependent and are assumed to change as follows :

$$P_L = P_{L0}(1+\lambda)$$
$$Q_L = Q_{L0}(1+\lambda) \quad (7)$$

where P_{L0} and Q_{L0} are the active and reactive base loads, whereas P_L, and Q_L, are the active and reactive loads at bus L for the current operating point as defined by λ.

V. Simulation Results

To analyze of static voltage stability to survey contingencies of power system (like the line outages and/or generation unit outages) with Psat software [13].

The continuation power flow for normal system manner is done that all generation units and lines are in the network and in fact no contingencies has occurred in system. Maximum Loading Point is λ_{max} = 3.97 *p.u.*

Also load active powers are in base and maximum cases are P_{base} = 3.626 *p.u.* and P_{max} = 10.29 *p.u.* respectively. The weakest bus also is identified bus14 with voltage 0.688 *p.u.*

A. The results of simulation for single generation unit outages with CPF method

Table I shows the results of single generation units outages applying continuation power flow.

As is shown in generation unit outages connected to bus 6, voltage magnitude in MLP in bus 14 that is known as the weakest bus is 0.528 *p.u.* note that in simulations, the generation unit connected to bus 1 that is known as slack bus does not exit from network.

TABLE I The Results of Single Generation Unit Outages.

Generation unit outage	Bus_No with lowest voltage magnitude	lowest voltage magnitude in MLP (p.u.)	λ_{max} (p.u.)	P_{load} (p.u.)	Q_{load} (p.u.)
Bus 2	5	0.72825	2.801	0.2122	0.0448
Bus 3	3	0.62359	2.89	2.7222	0.5492
Bus 6	14	0.52835	2.513	0.3744	0.1256
Bus 8	9	0.59134	3.451	1.0181	0.5728

The results of calculation of MWM for contingencies of generation unit outages in zero and one levels is shown in table II. Attention to (6), there are 5 contingencies in zero and first levels. In the first in contingency zero level that all system components are utilized correctly, system MWM is 6.67 *p.u.*

Contingencies ranking of first level based on their effects in continuum of generation unit outages in first level, we calculate system MWM in each manner. In generation unit outage connected to bus 6, MWM and its percent are 2.615 *p.u.* and 39.23% respectively that is lower than other generation unit outages.

TABLE II THE RESULTS OF MWM FOR GENERATION UNIT OUTAGES IN ZERO AND FIRST LEVELS.

level	Generation unit outage	P_{max} (p.u.)	P_{base} (p.u.)	MWM (p.u.)	MWM (%)
0	No contingency	10.2931	3.626	6.6671	100%
1	Bus 2	7.01	3.626	3.384	50.75%
1	Bus 3	7.4307	3.626	3.8047	57.06%
1	Bus 6	6.2416	3.626	2.6156	39.23%
1	Bus 8	8.8752	3.626	5.2492	78.73%

MLP and MWM decrease percent is provided in table III. Third and fourth columns of table show MLP and MWM decrease percent for single generation unit outages in first level respectively.

TABLE III CONTINGENCYS RANKING OF FIRST LEVEL IN SINGLE GENERATION UNIT OUTAGES.

Rank	Generation unit outage	λ_{max} (p.u.)	MWM decrease (%)
1	Bus 6	2.5133	60.77%
2	Bus 2	2.80108	49.25%
3	Bus 3	2.89057	42.94%
4	Bus 8	3.4511	21.27%

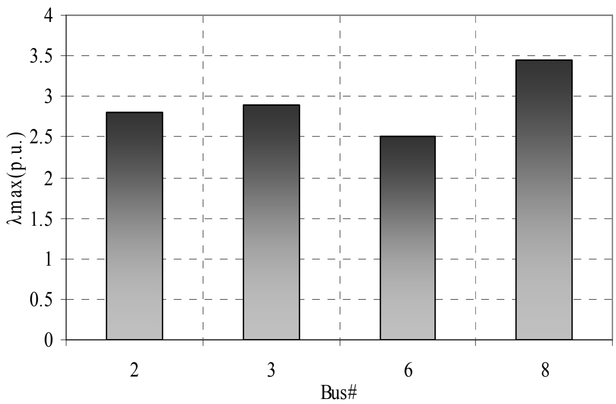

Fig. 4 MLP in single generation unit outages.

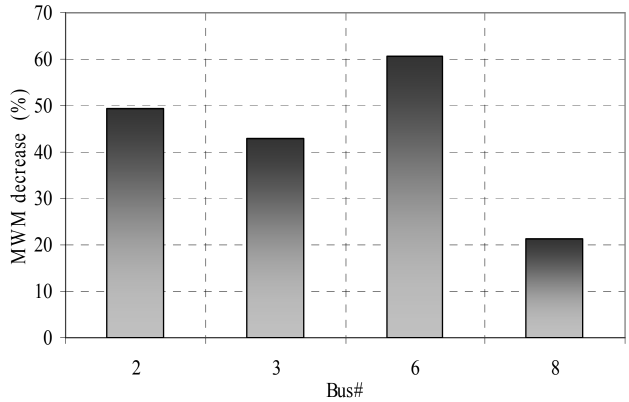

Fig. 5 MWM decrease percent in single generation unit outages.

Contingencies with lowest MLP and highest MWM decrease percent are in higher rank in table. In fact, these severe contingencies can cause to lose system stability and preparing insufficient power to avoid static voltage collapse.

Attention to table III, the generation unit outage connected to bus 6 with λ_{max} =2.513 *p.u.* and MWM decrease percent 60.77% are identified as the most critical contingency between contingencies of other generation unit outages.

So in table put in higher rank. As so contingencies of generation unit outage connected to buses 2,3 and 8 are in lower ranks in table. Figures 4 and 5 show MLP and MWM decrease percent in single generation unit outages.

B. The Simulation results of single line outages with CPF method

Results of single line outages applying continuation power flow are shown in table IV.

It is observed that the position of the weakest bus in no contingency (bus 14) has changed in 50 % of outages. The outage of line 11 connected to bus 1 to 2 has lowest MLP that in this manner bus 5 is identified as the weakest bus.

The results of calculated MWM for contingencies of line outages in zero and first levels are shown in table V. Attention to (6), there are twenty one contingencies in zero and first levels. we set the calculation of MWM with the line outages in first level. Exiting line 11, MWM and its percent calculate 2.0697 *p.u.* and 31.04 % respectively that decrease more than to other line outages.

Table VI shows contingencies ranking of first level in line outages. Attention to table, outages of lines 11,12, 18 and 10 are considered as critical lines and are in higher ranks in table. The outage of Line 11 with λ_{max} =1.332 *p.u.* and MWM decrease percent 68.96% is identified as the most critical lines between other line outages. This line because of connection to slack bus (bus 1) and generation unit bus (bus 2) is under high loading, so its outage results in sudden voltage drop and more approximating the system to voltage collapse. Lines 3, 7, 2, 17, 15 and 13 with higher loading point and lower MWM decrease percent are in lower ranks in table.

The outage of line 3 with MWM decrease percent 1.08% is considered as contingency that has not too much effect on static voltage instability.

TABLE IV RESULTS OF SINGLE LINE OUTAGES.

line Outage	Bus_No with lowest voltage magnitude	lowest voltage magnitude in MLP (p.u.)	λ_{max} (p.u.)
Line 1	5	0.66586	3.37591
Line 2	14	0.65303	3.91803
Line 3	14	0.67206	3.96367
Line 4	14	0.5938	3.16705
Line 5	11	0.55107	3.4502
Line 6	10	0.56583	3.67052
Line 7	14	0.64897	3.94297
Line 8	14	0.5405	3.70133
Line 9	14	0.57142	3.24118
Line 10	9	0.54399	2.85216
Line 11	5	0.9021	1.33241
Line 12	4	0.83	2.2802
Line 13	4	0.68559	3.85118
Line 14	5	0.65394	3.59377
Line 15	14	0.67248	3.87326
Line 16	5	0.68127	3.14858
Line 17	14	0.82814	3.88083
Line 18	14	0.65584	2.25639
Line 19	14	0.70207	3.55135
Line 20	9	0.57034	3.44629

TABLE V THE RESULTS OF CALCULATION OF MWM FOR LINE OUTAGES IN ZERO AND FIRST LEVELS.

level	line Outage	P_{max} (p.u.)	P_{base} (p.u.)	MWM (p.u.)	MWM (%)
0	No contingency	10.2931	3.626	6.6671	100%
1	Line 1	8.6783	3.626	5.0523	75.78%
1	Line 2	10.1447	3.626	6.4887	97.32%
1	Line 3	10.2213	3.626	6.5953	98.92%
1	Line 4	8.2712	3.626	4.6452	69.67%
1	Line 5	9.0009	3.626	5.3749	80.61%
1	Line 6	9.52026	3.626	5.8946	88.41%
1	Line 7	10.1788	3.626	6.5528	98.28%
1	Line 8	9.5869	3.626	5.9609	89.40%
1	Line 9	8.2924	3.626	4.6664	69.99%
1	Line 10	7.4019	3.626	3.7759	56.63%
1	Line 11	5.6957	3.626	2.0697	31.04%
1	Line 12	5.7095	3.626	2.0835	31.28%
1	Line 13	9.8663	3.626	6.2403	93.59%
1	Line 14	9.3145	3.626	5.6885	85.32%
1	Line 15	9.9984	3.626	6.3724	95.58%
1	Line 16	8.2482	3.626	4.6222	69.33%
1	Line 17	10.0227	3.626	6.3967	95.94%
1	Line 18	6.2416	3.626	2.6156	39.23%
1	Line 19	9.1617	3.626	5.5357	83.03%
1	Line 20	8.8709	3.626	5.2449	78.66%

TABLE V I CONTINGENCIES RANKING OF FIRST LEVEL IN LINES OUTAGES.

rank	line Outage	λ_{max} (p.u.)	MWM decrease (%)
1	Line 11	1.33241	68.96%
2	Line 12	2.22802	68.72%
3	Line 18	2.25639	60.77%
4	Line 10	2.85216	43.37%
5	Line 16	3.14858	30.67%
6	Line 4	3.16705	30.33%
7	Line 9	3.24118	30.01%
8	Line 1	3.37591	24.22%
9	Line 20	3.44629	21.34%
10	Line 5	3.4502	19.39%
11	Line 19	3.55135	16.97%
12	Line 14	3.59377	14.68%
13	Line 6	3.67052	11.59%
14	Line 8	3.70133	10.60%
15	Line 13	3.85118	6.41%
16	Line 15	3.87326	4.42%
17	Line 17	3.88083	4.06%
18	Line 2	3.91803	2.68%
19	Line 7	3.94297	1.72%
20	Line 3	3.96368	1.08%

Figures 6 and 7 show MLP and MWM decrease percent in outage of single lines.

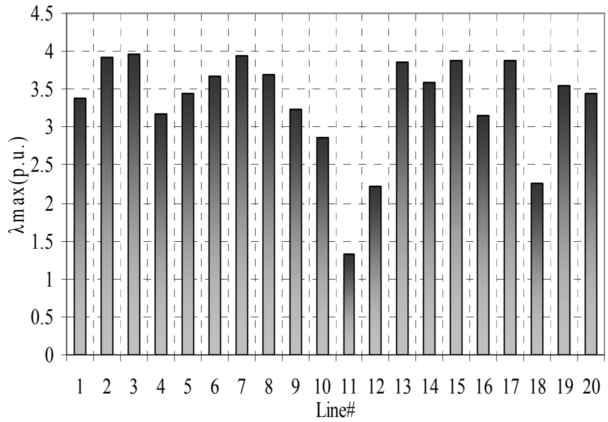

Fig. 6 MLP in single line outages.

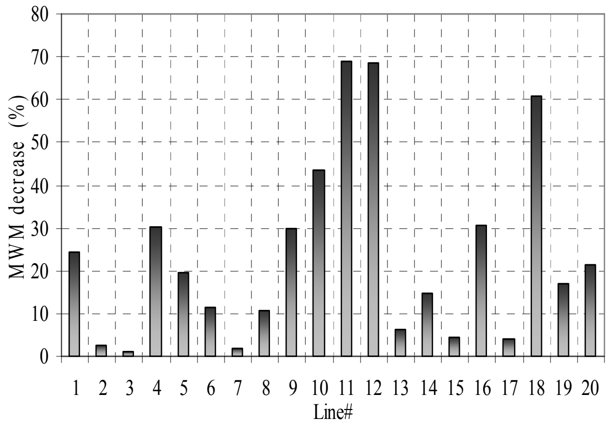

Fig. 7 MWM decrease percent in single line outages.

VI. CONCLUSION

In this paper to analyze static voltage stability, we set to surveying contingencies of power system (like line outages and generation unit outages) based on ranking these contingencies with continuation power flow method based on MLP and MWM decrease percent. The results show that the occurrence of contingencies in power system result in increasing of voltage drop in some of buses, the possibility of change in the weakest bus position, decrease of MLP and so its corresponding decrease of MWM. The contingencies with lower loading point and higher MWM decrease percent dedicates itself higher ranks. So with identifying these critical contingencies, we can do works to create preventive and reforming strategies to avoid system static voltage collapse.

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