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Estimation of Potential Outage Risk Evaluation of System using Performance Indices

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Abstract: Primary concern of power system is economical operation, but an equally defensive factor is the desire to maintain security. It is imperative to study the state of system by outage analysis and monitor its impact in advance to minimize the occurrence of cascaded disruptions. In power flow analysis the possibility of any error in measurement is not considered assuming all values as accurate. Due consideration is taken to minimize these errors adopting weighted Least square state estimation method incorporating synchronized PMU measurements. Overall severity index is the guideline selected in evaluating the stress on IEEE 5 and IEEE 14 bus systems. Highest indexed events are ranked on the top indicating too troublesome conditions leading the system towards risk.

Keywords: *System Security, Contingency Analysis, State Estimation, Phasor Measurement Unit.*

1. Introduction

The ultimate motive of power system is to maintain continuous supply to its stakeholders without any interruptions when components fail. Detection of dangerous situation of system need to be assessed quickly which is an essential mode of security assessment [1]. Unpredictable initiating events should not cause series of multiple actions which threatens the system security. Initiating hurdle may be one element outage termed as contingency. The response of outage scenarios on the system parameters must be investigated to initiate recovery action. Shortlisting the critical contingencies [2] from large list of credible contingencies are time consuming and tedious task. The operator faces lots of challenges in taking fast actions when many hurdles are observed in power system in a short duration leading to multiple problems. To overcome above problem most troublesome hurdles are to be ranked top in the list to accelerate the operator control action considering only necessary emergency cases. Index calculations are the guidelines adopted in assigning the top ranks to particular outages which cause more stress to the system [3]. Preplanned scenarios enable the operator to act defensively when hurdles arise in the form of outages.

Data gathered by the operator in control center has lots of errors. To emphasize the more accurate measurement proper procedure to be selected which in turn force the result to coincide more closely with the measurements of greater accuracy. Errors in meter is random in nature but must be within limit. We have to consider the errors in measured quantities for the purpose of power flow analysis [4]. Since there are errors in metered measured quantities, we will not be able to calculate ideal values of unknown quantities. So, estimate these values such that the effect of these measured errors is minimized [5]. Thus, measurements that come from instruments with good consistency will carry greater weight than measurements that come from less accuracy in instruments. The reduction in estimation error is the point of concern and need of the hour in modern era of power system. The conventional meters act as one of the bad data generating source and need to be controlled. PMU measurement will be the deliberate choice in reducing the undesired harmful effect of bad data on state estimation [6]. A unique feature of PMU in furnishing accurate phasor readings enhance its involvement in state estimation to reduce uncertainty.

2. Methodology

This paper involves simulation of IEEE Five bus system and IEEE Fourteen bus system based on Newton Raphson load flow method to obtain system parameters [7]. MI Power Simulation software is used as platform. Load flow problem consists of finding power flows and voltages of a network for given bus conditions. At each bus there are four quantities of interest to be known for further analysis: the real power and reactive power, voltage magnitude and its phase angle. Failure of one equipment is identified as N-1 contingency. One component outage may be either a transmission line, or a generator, or a transformer. The effect of single line outage on complete network is analyzed by Newton Raphson method. The procedure is

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continued till all line component outage cases are completed.

Estimation accuracy is computed by using weighted least square method with a modified Jacobian to deal with the phasor quantities. The covariance of state error vector or diagonal elements of gain matrix inverse in weighted Least Square method is utilized to gauge the status of estimation. From the point of view of state estimation PMU can furnish measurements related to voltage magnitude and phase angle, real and reactive power, real and reactive power flow [8]. Measurements and state variables are mathematically related as

$$z = h(x)+e \ldots\ldots.. (1)$$

Where z is set of measurement. h(x) is nonlinear function called measurement function which relates measurement to state variables. Measurement error is e. The WLS based estimator is to minimize the objective function

$$J(x) =[z - h(x)]^T R^{-1} [z - h(x)] \ldots. (2)$$

The gain matrix is calculated which depends on the Jacobian of measurement function h(x) computed by MATLAB [9-14].

To rectify the critical condition of system due to outages overall performance index is calculated considering active power, voltage magnitude and percentage loading performance indexes are [15-19]

Active Power performance Index is given by $PI_P=\sum_{i=1}^{N_L}\left(\frac{W}{2n}\right)\left(\frac{P_l}{P_l{}^{max}}\right)^{2n}$

Where,

P_l → MW Power Flow of Line l

$P_l{}^{max}$ → MW capacity of line l

N_L →Number of lines of the system

W → Real non-negative weighting factor, and value is (= 1)

n →Exponent of penalty function & value is (=1)

$P_l{}^{max} = \frac{V_i V_j}{X}$

Where,

V_i → Voltage at bus i^{th} obtained from the NR solution

V_j → Voltage at bus j^{th} obtained from the NR solution

X is the reactance of the line connecting i^{th} bus and j^{th} bus.

Voltage performance index (PIV) helps in determining bus voltages limit violation.

$$PI_V=\sum_{i=1}^{N_B}\left(\frac{W}{2n}\right)\left\{\left(\frac{|V_i|-|V_i{}^{sp}|}{\Delta V_i{}^{lim}}\right)\right\}^{2n}$$

Where, |Vi|→Voltage magnitude at i^{th} bus.

|Vi sp| → Specified (rated) voltage magnitude ati^{th}bus.

ΔV_i^{lim} → Deviation limit of the voltage.

n → Exponent of penalty function and value is (=1)

N_B → Number of buses in the system taken.

W → real non-negative weighting factor and the value is (= 1)

Overall performance index is calculated considering Active Power performance Index, Voltage performance index and percentage loading.

3. Result and Discussion

Figure 1a to 1h represents voltage magnitude estimation error and voltage angle estimation error in IEEE Five bus system with and without Phasor measurement unit for Base case and all line outage cases respectively. Voltage magnitude and angle Estimation errors are changed when PMU is added in base case and all line contingency conditions in measurement compared to without PMU.

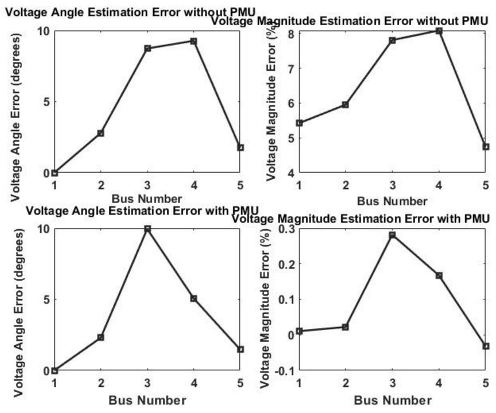

Fig 1a: Base case

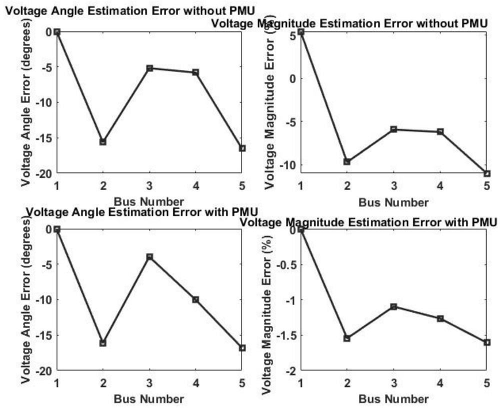

Fig 1b: Line 1-2 open

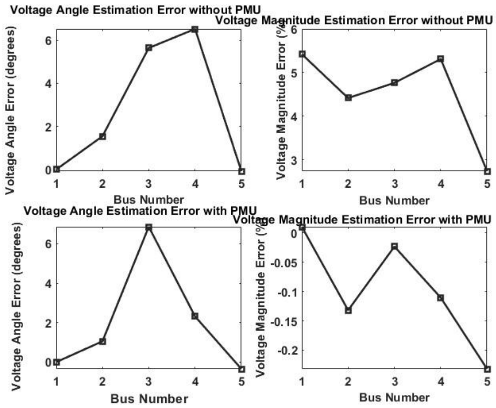

Fig 1c: Line 1-3 open

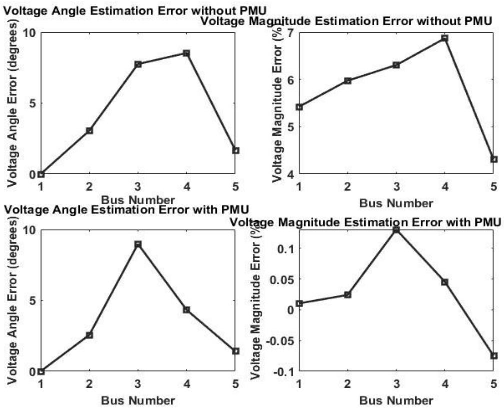

Fig 1d: Line 2-3 open

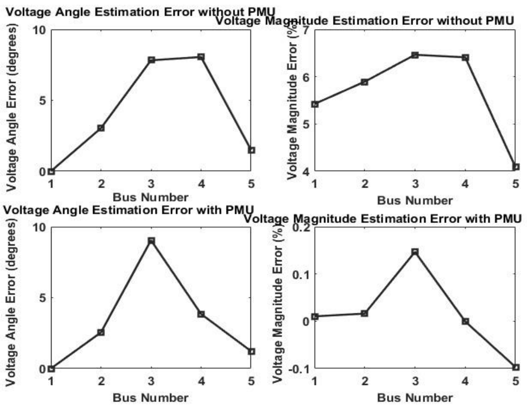

Fig 1e: Line 2-4 open

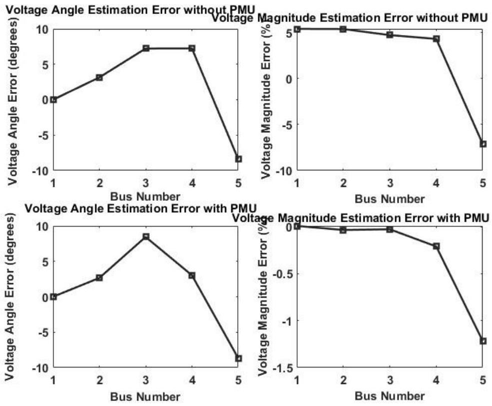

Fig 1f: Line 2-5 open

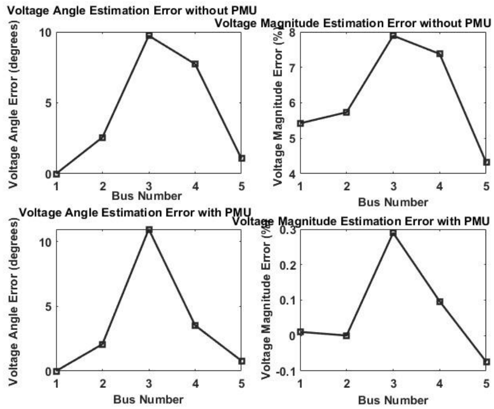

Fig 1g: Line 3-4 open

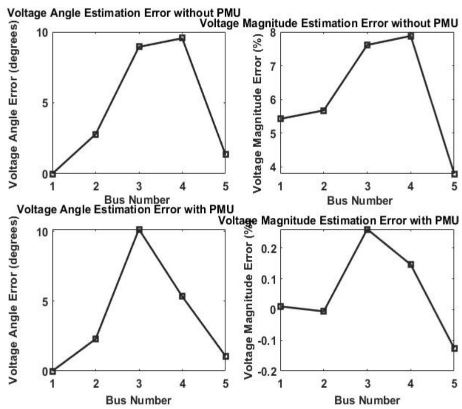

Fig 1h: Line 4-5 open

Table 2 indicates Sum of Overall Performance Index of IEEE Five bus system for all contingency conditions. Highest value of Sum of Overall Performance Index for line 1-3 signifies severely affected line with rank 1 and least value of Sum of Overall Performance Index for line 1-2 indicates that particular line is least affected with rank 7 when outage occurs. The priority for corrective actions to be given for those lines with highest SOPI and least priority with lowest value of SOPI.

Table 2: SOPI of IEEE Five bus system

SL. No	Lines	Line 1-2 open	Line 1-3 open	Line 2-3 open	Line 2-4 open	Line 2-5 open	Line 3-4 open	Line 4-5 open
1	Line 1-2	0	12.30846366	7.544917177	7.614248731	7.515367526	8.992763524	8.39719474
2	Line 2-5	3.596182884	4.890808722	4.689303931	4.890280279	0	4.729589428	4.785622252
3	Line 2-4	1.007295361	4.188752988	3.792810171	0	5.383561869	3.922848349	2.49410588
4	Line 2-3	1.995592256	4.30884505	0	3.699657949	4.583012079	1.539678867	2.299807381
5	Line 4-5	0.503955965	0.063741466	0.075591782	0.083549276	1.338407672	0.073602397	0
6	Line 1-3	0.583714024	0	0.15664721	0.154163094	0.176715014	0.103740884	0.122934189
7	Line 3-4	0.136591225	0.013767816	0.01477361	0.062528872	0.089143797	0	0.024155645
SOPI		7.823332	25.77438	16.27404	16.50443	19.08621	19.36222	18.12382
Ranking		7	1	6	5	3	2	4

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Figure 2a to 2s shows the voltage magnitude estimation error and voltage angle estimation error in IEEE Fourteen bus system with and without Phasor measurement unit.

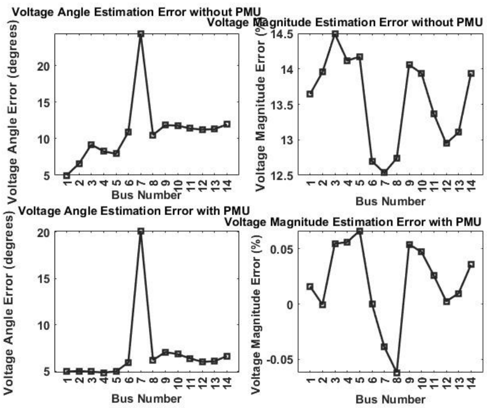

Fig 2a: Base case

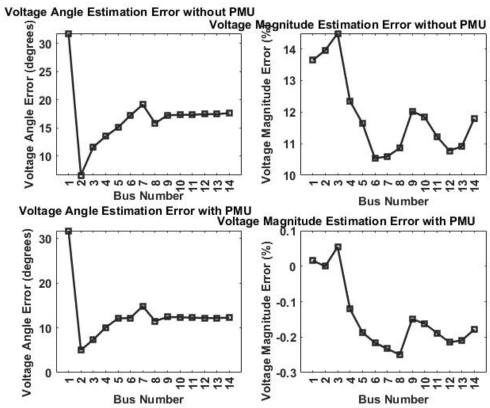

Fig 2b: Line 1-2 open

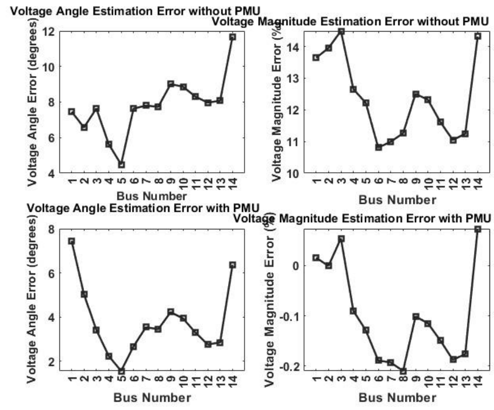

Fig 2c: Line 1-5 open

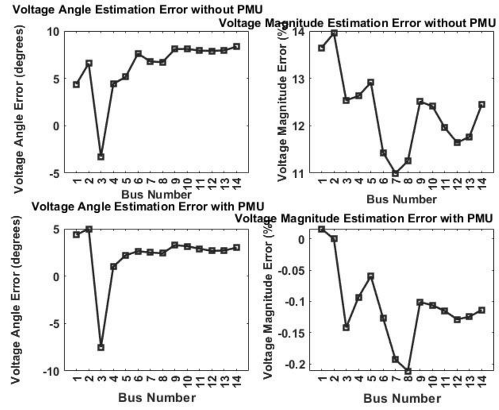

Fig 2d: Line 2-3 open

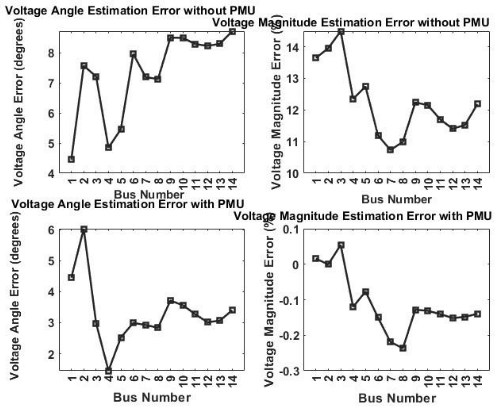

Fig 2e: Line 2-4 open

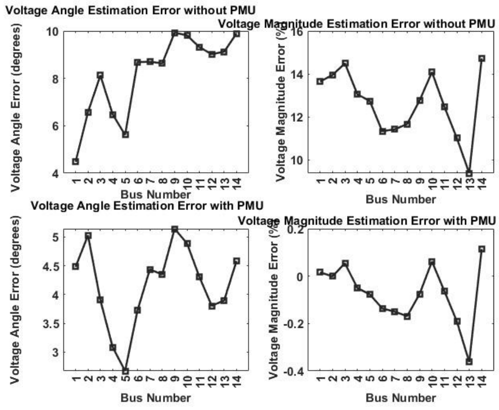

Fig 2f: Line 2-5 open

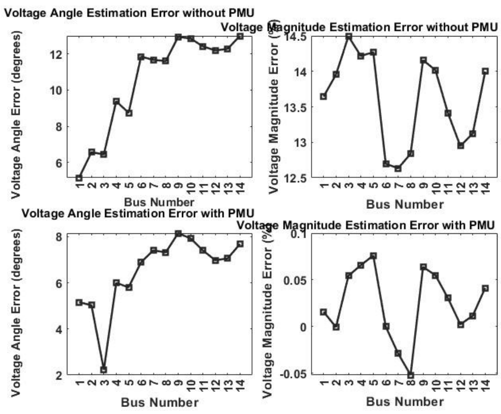

Fig 2g: Line 3-4 open

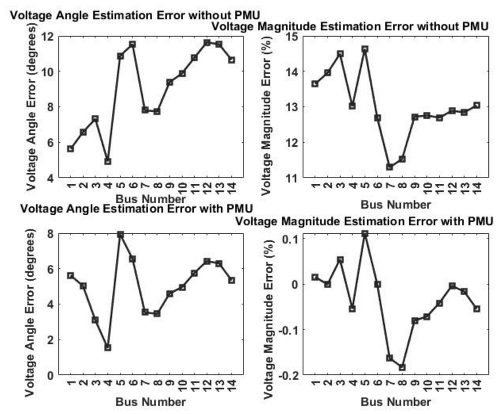

Fig 2h: Line 4-5 open

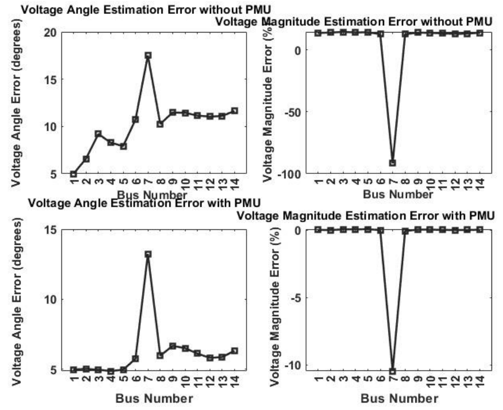

Fig 2i: Line 4-9 open

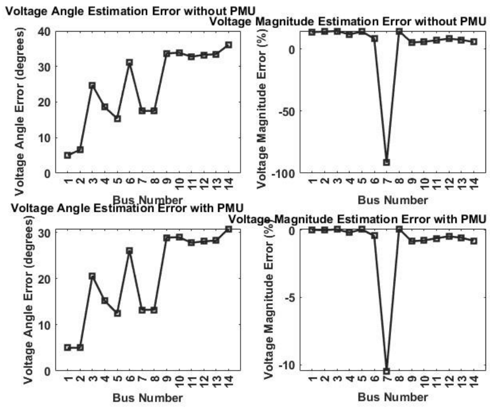

Fig 2j: Line 7-8 open

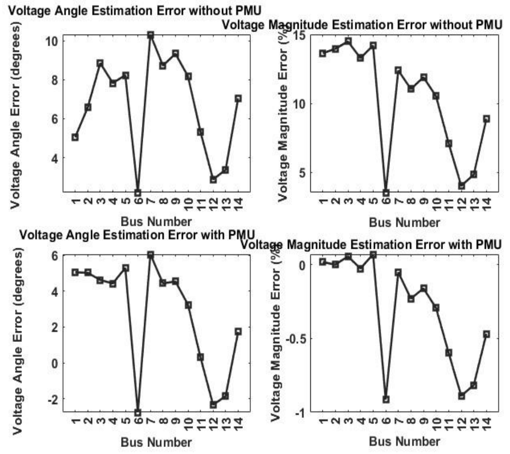

Fig 2k: Line 5-6 open

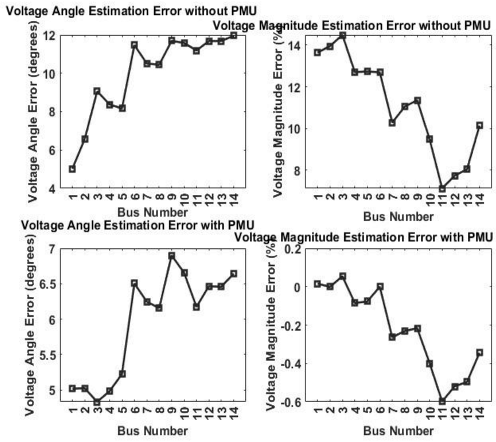

Fig 2l: Line 6-11 open

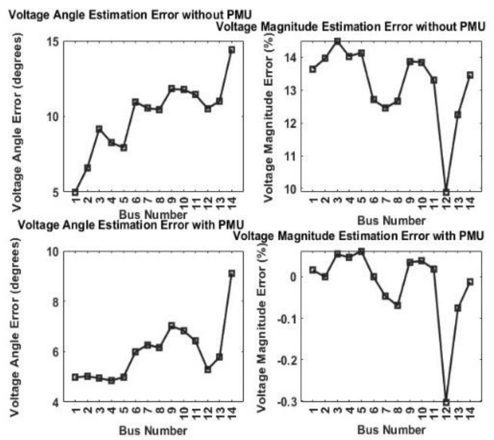

Fig 2m: Line 6-12 open

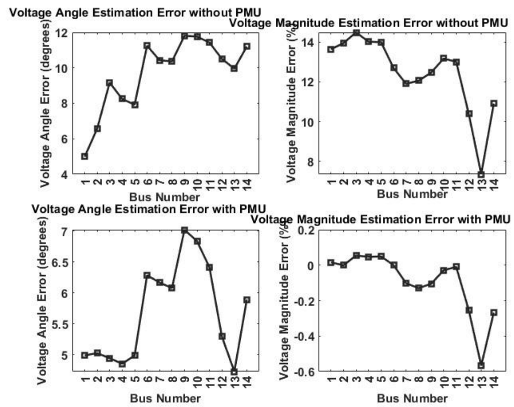

Fig 2n: Line 6-13 open

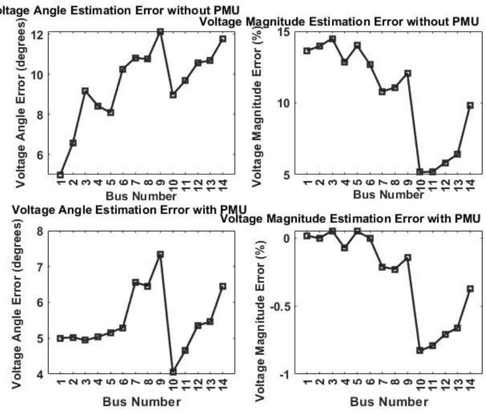

Fig 2o: Line 9-10 open

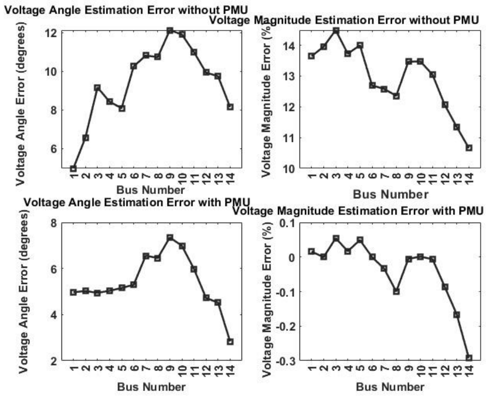

Fig 2p: Line 9-14 open

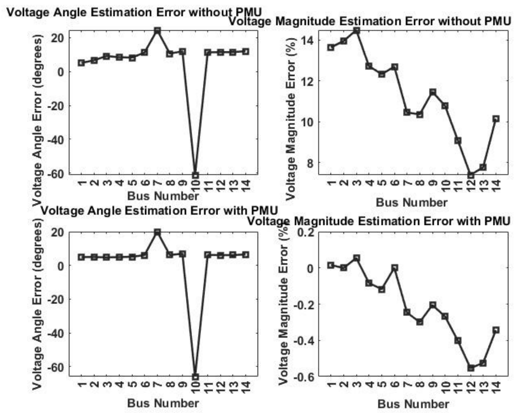

Fig 2q: Line 10-11 open

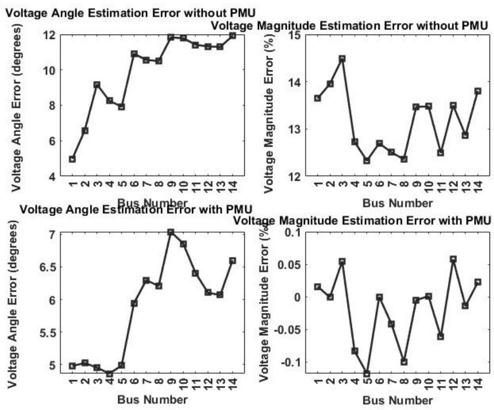

Fig 2r: Line 12-13 open

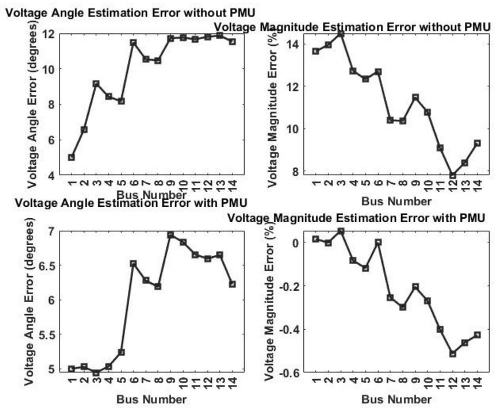

Fig 2s: Line 10-11 open

Table 3 represents Sum of Overall Performance Index of IEEE Fourteen bus system for all line contingency scenarios. Largest value of SOPI for line 9-10 is considered as highly affected line with rank 1 and smallest value of SOPI with rank 18 for line 1-5 indicates lowest affect when outage occurs.

Table 3: SOPI of IEEE Fourteen bus system

SL. No	Lines_ Open	SOPI	Ranking
1	Line 1-2	18.2404	10
2	Line 1-5	16.174	18
3	Line 2-3	17.4967	12
4	Line 2-4	17.0527	15
5	Line 2-5	16.7495	16
6	Line 3-4	16.5885	17
7	Line 4-5	17.9868	11
8	Line 4-9	17.4902	13
9	Line 5-6	24.5856	6
10	Line 6-11	22.1868	7
11	Line 6-12	19.7052	9
12	Line 6-13	17.3253	14
13	Line 7-8	21.6876	8
14	Line 9-10	28.5182	1
15	Line 9-14	28.0662	3

16	Line 10-11	27.9069	4
17	Line 12-13	24.9494	5
18	Line 13-14	28.4104	2

4. Conclusion

In this paper impact of line outages are investigated on IEEE Five bus system and IEEE Fourteen bus system by determining Overall Performance Index. In each line outage cases, lines with highest Overall Performance Index ranked on top indicating most severe case and lowest ranked case has least Overall Performance Index. Overall Performance Index is calculated based on cumulative effect of PI_P, PI_V and percentage loading. In an unplanned outage scenarios Overall Performance Index acts as a guideline for an operator in protecting system against highly critical cases. The efficacy of weighted Least Square voltage magnitude and angle estimation error reduced with PMU measurements against without PMU measurements. The combined solution of weighted Least Square estimation and PMU contributes major role in establishing Overall Performance Index as measurements extracted from instruments with small variance carry greater weight than measurements received from high variance instruments.

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