TJES

ISSN: 1813-162X
Tikrit Journal of Engineering Sciences
available online at: http://www.tj-es.com

Voltage Stability Analysis for Kurdistan Region Power System Using Fast Voltage Stability Index

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Received 30 January2012, Accepted 13 December 2012, Available online 18 September2013

ABSTRACT

In any stressed power system, Identification of the weakest bus and transmission lines is very important for planning and operation to prevent voltage collapse which leads to total blackout of the whole system. The aim of the paper is to use a technique to determine the weakest buses of the power system. Increasing load in power system could lead to the event of voltage collapse which implies the contingency in the system. Increasing load and line outage contingencies are ranked so that the line which highly affects the system could be identified. This paper proposes to utilize an established index called FVSI (Fast Voltage Stability Index) to identify the sensitive lines and critical line outages in the system. Test system of this paper is the KRPS-30-Bus-132kV. The contingency ranking process can be conducted by computing the line stability index of each line for a particular Increasing load and for line outage contingency. The contingency which is ranked the highest implies that it contributed to the system instability.

Keywords: Voltage Stability, Static Analysis, Kurdistan Region Power System (KRPS), Power System Analysis Toolbox (PSAT).

تحليل استقرارية الفولتية لمنظومة كهرباء اقليم كوردستان باستخدام مؤشر سريع لأستقرارية الفولتية

الخلاصة

في أي منظومة كهربائية تعتبر عملية تشخيص محطات و خطوط النقل الضعيفة من حيث استقرارية الفولتية هامة جدا من ناحية تخطيط و تشغيل المنظومة لمنع حدوث أنهيار الفولتية التي تسبب في أطفاء المنظومة بأكملها. ان الهدف من البحث هو استخدام تقنية لتحديد المحطات الضعيفة في المنظومة. أزدياد الحمل في المنظومات الكهربائية يؤدي الى حدوث أنهيار الفولتية المفهوم ضمنا بالحالة الطارئة للمنظومة. تم ترتيب حالات الأزدياد في الحمل و الخروج الطاريء للخطوط النقل و ذلك لتحديد الحالات التي لها تأثير كبير على المنظومة. هذا البحث يقترح استخدام مؤشر تسمى مؤشر سريع لأستقرارية الفولتية لتحديد الخطوط الحساسة و الحرجة في حالة خروجها من المنظومة.المنظومة المستخدمة في هذا البحث هي منظومة كهرباء اقليم كوردستان و التي تحتوي على 30-محطة 132 كيلو فولت ،عملية ترتيب الحالات الطارئة يمكن الحصول عليها عن طريق أيجاد عامل أستقرارية الفولتية لكل خط و لكل منطقة خاضعة لأزدياد الحمل و حالات خروج الطارئة للخطوط و الحالة الطارئة التي لها أعلى مرتبة يفهم ضمنا بأنها تساهم في أنعدام الاستقرارية.

الكلمات الدلة: استقرارية الفولتية، التحليل الساكن، مؤشر سريع لاستقرارية الفولتية، منظومة كهرباء اقليم كردستان، كتاب أدوات نظم تحليل القدرة .

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Introduction

Voltage stability has been recognized as a very important issue for operating power systems when the continuous load increase along with economic and environmental constraints has led to systems to operate close to their limits including voltage stability limit [1]. A system enters the state of voltage instability when an increase in load demand or change in system condition causes a progressive and uncontrollable fall of voltage. Load variations or contingencies in general cause voltage collapse [2]. Voltage collapse is usually characterized by an initial slow and progressive decrease and a final rapid decline in voltage magnitude at different buses [3]. Therefore, the robustness of power transmission networks under considering voltage stability problem is important and considered in the deregulated and competitive environment. In recent years, there are many approaches to assess voltage stability problem [4]. Static analysis methods could be used to analyze voltage stability problems approximately, several voltage stability indices derived from static power flow analysis were proposed for power systems. The values of the indices were calculated for each distribution line based on load flow results [5]. 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. Ranking all possible increasing in load of different areas 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 [6].

In [4] a fast calculation of a voltage stability index using the minimum singular value and the corresponding left and right singular vectors is presented. In [7] the results obtained from the load flow analysis will be utilized to compute the voltage stability index and ranking of the line outage contingencies. The work done in [8] shows that the FVSI index can be used as an indicator for under voltage load shading relay location, in which the FVSI index is capable to identify critical areas in a system. Thus, load shedding at these points does improve the stability of the system.

In this paper voltage stability analysis is conducted using a methodology which is essentially based on predicting voltage instability in the power system using fast voltage stability index (FVSI); its values indicate the voltage stability condition in a power system for a particular load demand. Calculating FVSI for increasing in load demand for a growing region and contingency of line outages plus increasing in load (double stressed) is also implemented.

The line stability index is tested on KRPS 30-Bus system, for base case, different loading cases, and for double stressed condition case.

The results obtained from the load flow analysis (using NR method) will be utilized for computing the voltage stability index.

Methodology

In This paper simulations were carried out using PSAT Simulation Tool which is a Matlab toolbox for electric power system analysis and control. PSAT includes power flow, continuation power flow, ect.. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design [9], 30- Bus Kurdistan region power system is used as the test system for analyzing voltage stability.

FVSI (Fast Voltage Stability Index)

Voltage stability indices are invaluable tools for gauging the proximity of a given operating point to voltage instability [10]. The FVSI index was derived based on the general two-bus representation which is shown in Fig.1.

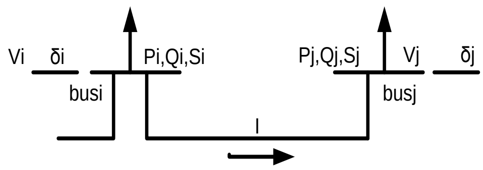

Fig.1. Two bus power system model [11].

The index for Fast Voltage Stability is given as follows [8]:

$$FVSI_{ij} = \frac{4Z^2Q_j}{V_i^2X}$$

The symbols 'i' represents the sending bus while 'j' represents the receiving bus whereas Z is the line impedance, X is the line reactance, R is line resistance, Qj is the reactive power at the receiving end, and Vi is the sending end voltage.

The line stability indices are evaluated for different cases. The values of line stability index would indicate the voltage stability condition in a power system for a particular load demand [7].

Line stability indices values which approach 1.00 imply that the power system approaches its voltage stability limit [11].

Tables were developed from the results obtained for FVSI for each loading case; stability condition will be ranked. From the ranking table, the effect of increasing load at an area on voltage stability, the effect of line outage contingency and increasing load on voltage stability condition of a system could be determined.

Kr -Power System

Kurdistan region forms the three northern governorates of Iraq; they are Sulaimany(area-1), Erbil (area-2), Duhoke(area-3), and It is bounded by Iran from east, Turkey from north, and by Kirkuk , Diala and Mosel governorates from west and south.

Fig.(2) illustrated KR 30-Bus HV power system (using PSAT Simulink library) which is consisting of five generation Buses, 25 load Buses and 42 HV transmission lines. Bus No. 1 is chosen as a slack Bus.

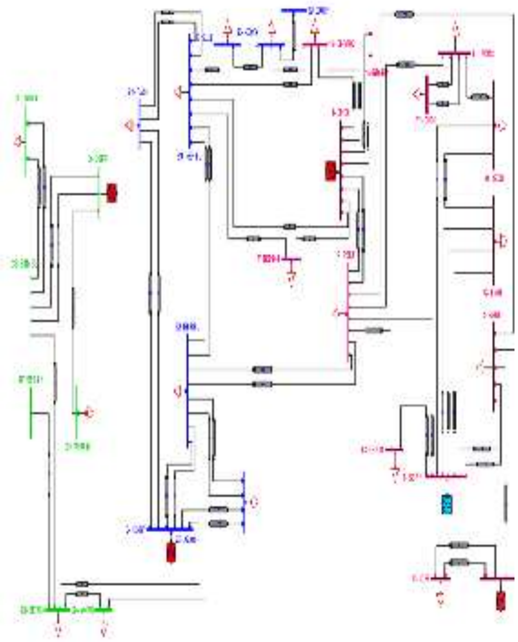

Fig.2. KRPS 30-bus power system.

Voltage Stability Analysis

The following scenarios were created to analyze the voltage stability of the system.

<u>A) Base case:</u> Generally, high FVSI value indicates critical lines in a base case.

<u>B) Transmission line stressed case:</u> The load demand is increased gradually in three different areas as following:

1. Load in area-1 increased to 185%.
2. Load in area-2 increased to 265%.
3. Load in area-3 increased to 300 %

In table (1) FVSI for normal loading case is calculated from the results it’s clear that the transmission lines located between buses (14 – 22, 14-4 and1-10) are the most unstable line in the system respectively, and other lines in the system are at stable condition. This result is more clearly shown in Fig.(3).

Table 1. FVSI for normal loading case

Line No.	From	To	FVSI
1	1	13	0.007736
2	1	10	0.130192
3	1	9	0.056827
4	1	8	0.084547
5	4	15	0.000415
6	4	16	0.026692
7	4	17	0.001687
8	4	20	-0.09782
9	5	8	-0.00401
10	5	7	0.026093
11	5	6	0.041458
12	14	1	0.091331
13	14	13	0.084232
14	14	22	-0.16194
15	14	11	0.060792
16	14	4	-0.1579
17	11	10	0.001182
18	11	12	0.002075
19	14	8	0.026312
20	9	10	0.029756
21	8	7	0.019981
22	2	21	0.018652
23	2	21	0.017813
24	2	22	0.072553
25	2	23	0.067466
26	2	25	0.014206
27	21	20	0.057514
28	22	20	0.001792
29	22	23	-0.00638
30	23	24	-0.01685
31	20	19	0.057202
32	20	16	0.076564
33	20	17	0.085906
34	19	18	0.054807
35	18	29	-0.00139
36	18	16	0.004898
37	25	27	0.0048

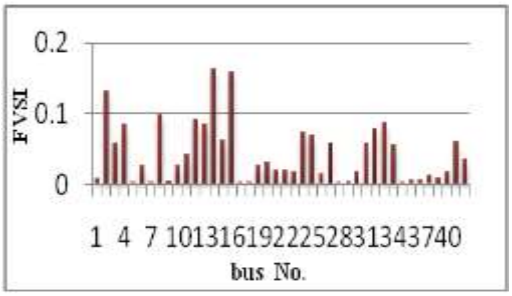

Fig.3.Transmission lines FVSI (Normal Load).

For case B, noting Table (2); load increased in area-1 up to 185%; the transmission lines located between buses (1-10, 14-4 and 1–8) are the most unstable line in the system respectively ,it's good to say that these lines are located in that area which load increased.

Table 1. FVSI for normal loading case

Line No.	From	To	FVSI
1	1	13	0.007736
2	1	10	0.130192
3	1	9	0.056827
4	1	8	0.084547
5	4	15	0.000415
6	4	16	0.026692
7	4	17	0.001687
8	4	20	-0.09782
9	5	8	-0.00401
10	5	7	0.026093
11	5	6	0.041458
12	14	1	0.091331
13	14	13	0.084232
14	14	22	-0.16194
15	14	11	0.060792
16	14	4	-0.1579
17	11	10	0.001182
18	11	12	0.002075
19	14	8	0.026312
20	9	10	0.029756
21	8	7	0.019981
22	2	21	0.018652
23	2	21	0.017813
24	2	22	0.072553
25	2	23	0.067466
26	2	25	0.014206
27	21	20	0.057514
28	22	20	0.001792
29	22	23	-0.00638
30	23	24	-0.01685
31	20	19	0.057202
32	20	16	0.076564
33	20	17	0.085906
34	19	18	0.054807
35	18	29	-0.00139
36	18	16	0.004898
37	25	27	0.0048
38	25	28	-0.01182
39	3	28	0.008476
40	3	26	0.016602
41	24	25	-0.06038
42	28	30	0.034942

In table(2) Load increased in area-2 up to 265%;noting fifth column, the transmission lines located between buses (14-4, 1-10 and 14 – 1) are the most critical lines in the system respectively and the line located between buses (14-4) exceeds the stability limits .when Load increased in area-3 up to 300%; In Table (2) the transmission lines located between buses (24-25, 14-4 and 1 – 10) are now the critical lines in the system ,although the indices value doesn't exceeds 0.4 and that's because in this area the load is small when compared with the generation .

(C)Multiple contingency

It can be seen clearly that for a large system, multiple contingency is needed to make the FVSI value to reach close to 1.so for further stress and to analyze the FVSI index, multiple contingency were carried out. This contingency includes transmission line outage and load demand increase in the whole system:

a- Each single line is out of the system with base load of the system.
b- Each single line is out of the system and load of the system increased to 1.2.
c- Each single line is out of the system and load of the system increased to 1.5.

And the results tabulated in table (3).

Table 3. FVSI for multiple contingency

line outage	base case		base case *1.2		base case*1.5	
from-to	from-to	FVSI	from-to	FVSI	from-to	FVSI
1—13	1--14	0.481	1--14	0.82	1—14	0.89
1—10	1--14	0.464	22--14	0.25	11—14	0.68
1—9	1--14	0.361	14--4	0.26	14--4	0.51
1—8	1--9	0.127	14--1	0.24	14--1	0.57
4—15		NR		NR		NR
4—16	20--16	0.202	20--16	0.31	20--16	0.57
4—17	14--22	0.15	4--3	0.23	14-4	0.46
4—20	14--22	0.154	14--22	0.45	14--4	0.45
5—8	14--22	0.154	1--10	0.19	1--10	0.37
5—7	14--22	0.164	14--4	0.23	14--4	0.46
5—6	14--22	0.152	14--2	0.22	14--4	0.42
14—1	14--13	0.212	14--13	0.42	14--13	1.13
14--13	14--22	0.182	14--1	0.30	14--1	0.72
14--22	14-4	0.198	20--16	0.30	20--16	0.58
14--11	1--10	0.181	1--10	0.24	14--4	0.44
14—4	14-22	0.173	1--10	0.28		NR
11--10	14--22	0.194	14--4	0.32	14--1	0.58
11--12		NR		NR		NR
14—8	14--22	0.166	14--4	0.33	14--1	0.57
9—10	14--22	0.162	14--4	0.25	1--10	0.48
8—7	14--22	0.15	14--4	0.23	14--4	0.44
2—21	14--22	0.145	14--4	0.23	14--4	0.44
2—21	14--23	0.145	14--4	1.23	14--4	0.44
2—22	14--4	0.14	14--4	0.23	14--4	0.45
2—23	14--4	0.14	14--4	0.24	14--4	0.45
2—25	14--22	0.152	14--4	0.23	14--4	0.44
21--20	14--4	0.143	14-4	0.24	14--4	0.45
22--20	14--22	0.161	14--4	0.23	14--4	0.43
22--23	14--22	0.149	14--4	0.23	14--4	0.44
23--24	14--22	0.153	14--4	0.23	4--41	0.44
20--19	18--16	0.336	18--16	0.64		NR
20--13	14--22	0.153	14--4	0.23	4--14	0.44
17--20	14--22	0.155	14--4	0.23	4--14	0.44

18--19	14--22	0.155	14--4	0.23	4--14	0.43
18--29	14=22	0.153	14--4	0.23	4--14	0.43
18--16	14=22	0.15	14--4	0.23	4--14	0.45
25--27	14=22	0.15	14--4	0.22	4--14	0.41
25--28		NR		NR		NR
3—28		NR		NR		NR
3—26	14=22	0.142	14--4	0.20	4--14	0.37
24--25	14=22	0.149	14--4	0.23	4--14	0.44
28--30	14=22	0.153	14--4	0.23	4--14	0.43

In which the simulation result are shown when lines(4-15,11-12,25-28,3-28) are out the system is in not running(NR) condition , in table (4) ranking of forth most critical lines are shown.

From which: it's clear that line outage of (1-13) is the most critical line in the system for all cases, when the mentioned line is out then line (1-14) is near its stability limits.

Results and Discussion

Base case loading, case of increasing load and multiple contingency cases were taken in considerations to evaluate voltage stability using FVSI. As expected, the corresponding FVSI value increases due to increase in real and reactive power demand. The FVSI values for the system are at the highest values when compared to the base case.

The line stability indices were computed and the results are tabulated in Tables 1, 2. The values of line stability indices highlighted in the tables indicate the highest indices. Referring to table 1; transmission lines (14 – 22, 14-4 and1-10) are the most unstable line in the system respectively.

Referring to table 2 and taking column 4; when area-1 load is increased, the proposed line stability index is evaluated; the evaluation show that the positions of most sever line is changed to line (1-10) and the result yields the line stability index value for line (1-10) is the highest which 0.939682. It shows that this line is approaching its voltage stability limit, and this is because of this line is one of the most heavy loaded lines, bus 10 is most heavy loaded bus, and this line is located in area-1. Taking column 2 in table 2; when area-2 load is increased to about 2.6 times base case, its observed that the line (14-4) is the most sever line, and its FVSI= 1.131, this shows that this line is exceeding its voltage stability limit.

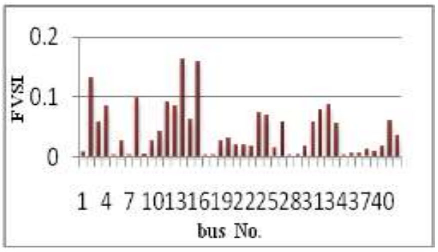

Fig.3. Transmission lines FVSI (Normal Load).

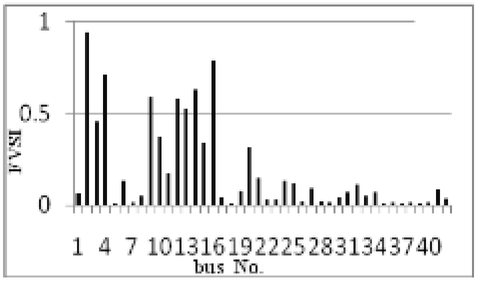

Fig.4. Transmission lines FVSI (Area-1 increased Load).

Noting seventh column in table (2) it's clear that line (24-25) is the most critical line, generally none of the lines approaching stability limits.

The contingency ranking for the three cases mentioned (c) were based on line stability values evaluated for each loading condition. The computation was performed by taking line outage 1 through 42 for each different case. The line stability indices were computed and the results are tabulated in Table (3). Referring to table 3 and taking base case; when line (1-13) is outage, the proposed line stability index is evaluated for each line in the system and the result yields the line stability index value for line (1-14) is the highest which is equal to 0.481. However, it can be seen that outage in line (4-15,11-12,25-28,3-26) gives non convergence result 'NR' (no result) indicates voltage collapse has occurred when these lines outage . Line outage which resulted in voltage instability is ranked from the highest for multiple stressed as shown in table (4).

Table 4. Line Outage Contingency Ranking

rank	cases		
	Base	Load increased to *1.2	Load increased to *1.5
1	1--13	1--13	1--13
2	1--10	9--10	9--10
3	1--9	8--7	8--7
4	20--19	5--8	5--8

Conclusions

Power system stability is an important factor in a power system. Static analysis methods could be used to analyze voltage stability problems. A fast voltage stability index FVSI was used in this work. An investigation was carried out to see the effectiveness of load increment, line outage contingency on the line FVSI .The FVSI determines the critical line in a system. A line is considered to be critical if the voltage stability index referred to this line closes to 1.00.
Simulation studies conducted to KRPS shows that a FVSI index increases as the system becomes stressed and further increase if the system attacked to multiple contingency. Although the FVSI value obtained is small compared to the value of 1(critical bus) but it gives a clear indication of critical busses whereby the FVSI value is relatively higher at the critical buses.
The results in table (4) show that the outage of line (1-13) has a hight FVSI in all cases. The contingency ranking could assist the operating engineer to take necessary actions in order to avoid the occurrence of voltage collapse in the system.

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