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Assessment of Voltage Stability Index to various loading conditions and Electrical Vehicle Charging Station Load on Distribution network

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Abstract: EVs are a good substitute to reduce the emissions produced by the transportation industry. Charging stations have been set up as EVs become more and more popular. however, it is impossible to ignore the negative effects that EV charging station loads have on the distribution network's voltage stability. In this research, an analysis of two voltage stability indicators (VSIs) is provided to forecast the distributions near voltage collapse. These VSIs are based on the idea of the two-bus voltage quadratic equation. Radial distribution systems (RDS) IEEE 15-bus test system was used to assess the behavior of VSIs as base load penetration increased. These indices are differentiated to determine how well they can determine the system's weakest bus. Results indicate that this evaluation of the indices can be used to position EV chargers in the system.

Keywords: Distribution network, Voltage Stability indices, EVs Charging Station, voltage collapse.

1. INTRODUCTION

In the current days, due to increasing global warming, gas house emissions, and crude oil prices, an electric vehicle is a good option in the transportation sector which replaces the IC engine vehicle. But now due to the growing number of electric vehicles, the increase in charging station load has many effects on the radial distribution system such as loss, voltage problems, load increase, harmonics, stability issues, etc. However, it is impossible to ignore the increased EV charging station loads' negative effects on the distribution system. effect of EV charging station loads on distribution networks' voltage stability.

Voltage instability has reportedly been cited as the primary reason for power system blackouts around the world in recent years. Voltage collapse is another term for voltage instability. Increased load demand is one of the main reasons for voltage instability.

Voltage stability is essential to the stability of the power system. This study evaluates multiple voltage stability indices (VSIs) to forecast when the distribution bus will be near to voltage collapse. The Voltage Stability Index includes VSI and SI. These VSIs are based on the principle of the two-bus voltage quadratic equation. Radial distribution systems (RDS) IEEE 15-bus test system was used to assess the behavior of VSIs as base load penetration increased. The usage of these voltage stability indices helps in locating the system's weak buses. The bus is classified as the weak bus in the system if its VSI value is near to the critical value.

The paper's primary goal was to identify the weak bus in the power system using an evaluation of the Voltage Stability Index. The use of VSIs can be utilized to plan the power system network and locate the best place for EV chargers. The rest of the paper is arranged as follows. Section 2 reviews the two various VSIs. Section 3 in IEEE 15- bus RDS. Section 4 discusses the results of different loading conditions (EVs) and finally, the conclusion is drawn in section IV.

2. VOLTAGE STABILITY INDICES

Voltage stability indices (VSI) are the scalar quantity that outlines the state of voltage stability of power system networks. Additionally, they identify the bus or lines that are weaker and monitor the difference between a specific operating point and voltage collapse. The power system operator can take specific preventive measures with the use of VSI. System variables are classified depending on VSI. The maximum loading point of a system is computed as well as

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the voltage stability margin using a VSI. As they use power system variables like bus voltages and line power flows, VSI based on system variables requires the least amount of computing time. These VSIs are used for online monitoring and assessment since they can measure stability with the least amount of computing time.

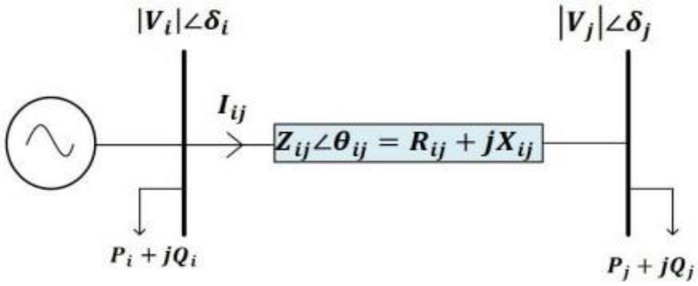

Figure 2.1 Single-line diagram of a two-bus system

Where,

- R_{ij} X_{ij} , are the resistance and reactance of the line connected between sending and receiving buses.
- Q_j P_j , are the reactive and active power at receiving bus.
- Q_i P_i , are the reactive and active power at sending bus.
- V_i is a voltage at sending bus.
- V_j is a voltage at receiving bus.

I. Voltage stability index [03]

The VSI developed by Charkravorty and Das is evaluated to determine RDS's voltage stability. In radial distribution networks, determine the stability index for each receiving end bus. The following is the mathematical expression for VSI:

VSI eq:

$$V_i^4 - 4V_j^2(P_{Lj}R_{ij} + Q_{Lj}X_{ij}) - 4(P_{Lj}X_{ij} + Q_{Lj}R_{ij})^2 \geq 0 \ldots\ldots (01)$$

When VSI(j) > 0, the buses of the radial distribution network are also stable.

II. Stability index [04]

One can assess the stability of radial distribution networks using this voltage stability index, and if the index shows a low level of stability, necessary action may be taken. The following is the mathematical expression for SI:

SI eq: -

$$2V_i^2V_j^2 - V_j^4 - 2V_j^2(P_jR_{ij} + Q_jX_{ij}) - Z_{ij}^2(P_j^2 + Q_j^2) \geq 0 \ldots\ldots (02)$$

If the bus' SI value is the lowest, it is weak to voltage collapse.

This research carefully examines the comparability of two Voltage Stability Indices.

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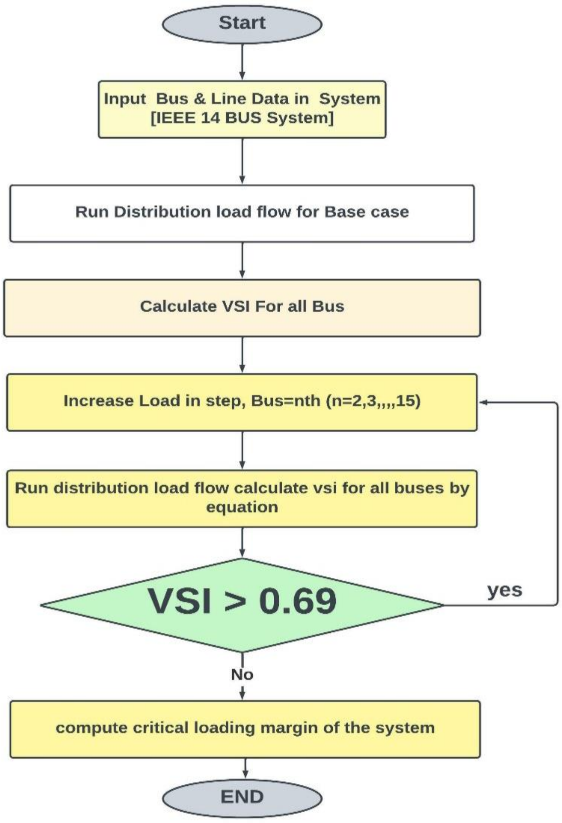

Fig 2.2 Flowchart for computation of stability index

3. Test System

14 load buses, 1 swing bus, and 14 branches make up the IEEE 15 bus RDS. Under standard test conditions, the test system has total active and reactive power demands of 1226.4 kW and 1251.11 kVAr, respectively. Fig. 2 shows the single-line diagram representation of this test system. The parameters of the IEEE-15 bus system are shown in Table 1. The IEEE15 bus system a clearly defined distribution network. Math work is used to reference the necessary bus and line data for IEEE 15 bus RDS.

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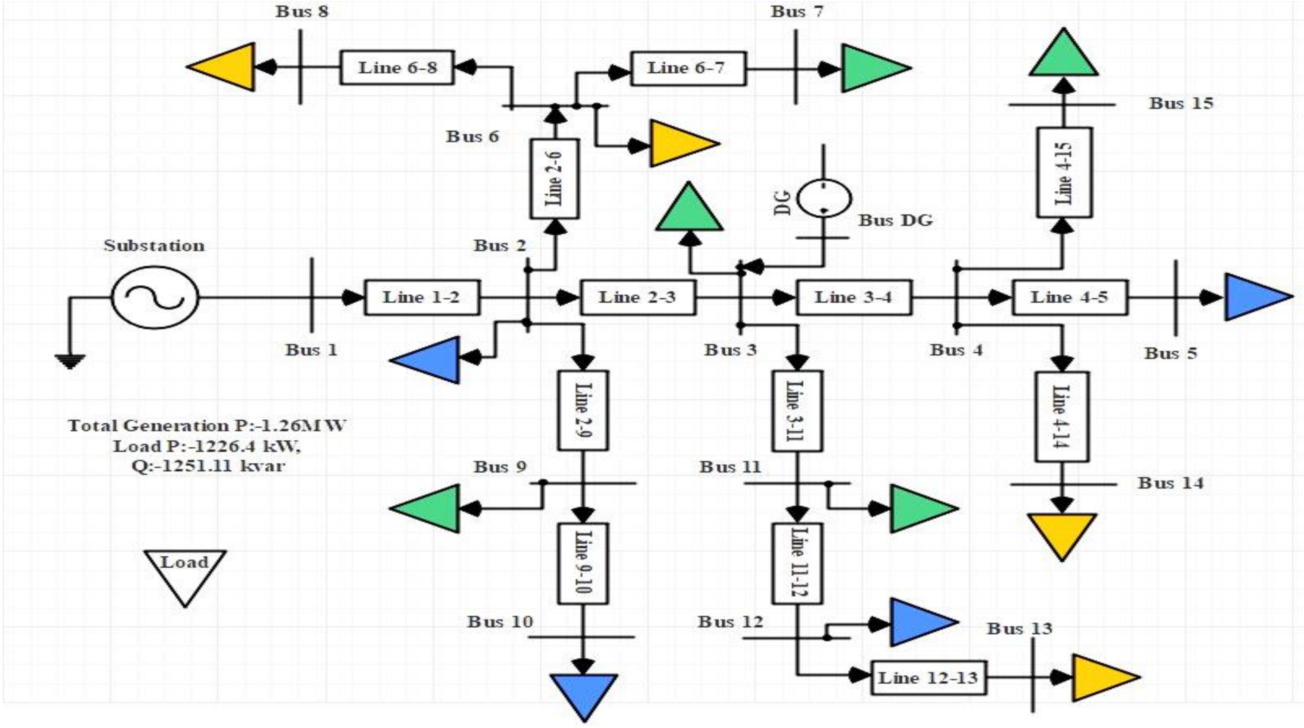

Figure 3.1. single line diagram of IEEE 15 bus system

Sr. No.	Line	BUS No.	R(ohm)	L	P(kW)	Q(kW)
1	1-2	2	1.3	0.0035	44.1	44.99
2	2-3	3	1.17	0.0030	70	71.41
3	3-4	4	0.84	0.0021	140	142.82
4	4-5	5	1.53	0.00275	44.1	44.99
5	2-6	6	2.557	0.004	140	142.82
6	6-7	7	1.088	0.0019	70	71.41
7	6-8	8	1.25	0.002	140	142.82
8	2-9	9	2.013	0.003	70	71.41
9	9-10	10	1.68	0.0031	44.1	44.99
10	3-11	11	1.79	0.0032	70	71.41
11	11-12	12	2.448	0.004	44.1	44.99
12	12-13	13	2.01	0.003	140	142.82
13	4-14	14	2.2308	0.00399	140	142.82
14	4-15	15	1.197	0.00214	70	71.41

Table 3.1 IEEE 15 bus system Bus load and line Data

4. VOLTAGE ANALYSIS AND RESULTS

In this system 11 kV RMS voltage, Voltage magnitude is measure using a Phasor measurement unit. The load flow study produced the voltage profile of the IEEE 15 bus RDS with nominal demand, which is displayed in Fig. 3.

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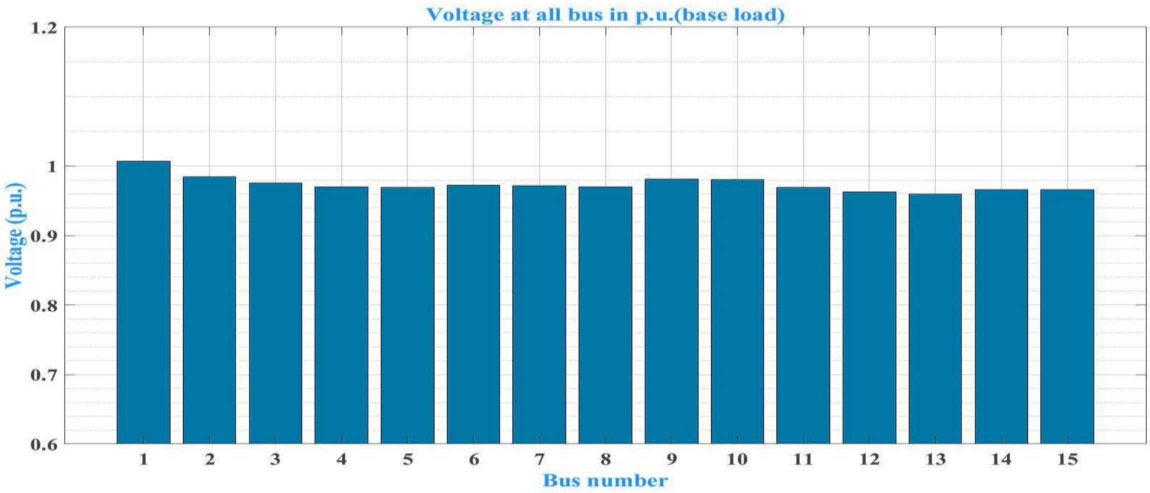

Figure 4.1 IEEE 15 bus system Voltage at all bus in per unit

4.1. The study of various bus voltage stability indices is demonstrated in Nine (9) cases.

The various VSIs described in section 2 have conducted testing on IEEE 15 bus RDS test systems to show their efficiency. Nine cases are utilized in this research to demonstrate the examination of various Bus VSIs. They are listed below.

Case 1: System with the base caseload.
Case 2: System with 105% of the base caseload.
Case 3: System with 110% of the base caseload.
Case 4: System with 115% of the base caseload.
Case 5: System with 120% of the base caseload.
Case 6: System with 125% of the base caseload.
Case 7: System with 130% of the base caseload.
Case 8: System with 140% of the base caseload.
Case 9: System with 150% of the base caseload.

MATLAB software was utilized to perform the simulation to determine the most sensitive index for recognizing the Bus that is on near voltage collapse. The investigation was conducted under conditions of increased loading, i.e., 105%, 110%, 115%, 120%, 125%, 130%, 140%, and 150% of the base load. The system's active power load is taken into account simultaneously with the increase. The results for the voltage profile, VSI, and SI for each case study are shown in Tables II, III, and IV, respectively. It is discovered that SI and VSIs classify bus 2 as the system's strong bus and bus 13 as its weak bus. Bus 13 and Bus 2 have different voltages that are lower and higher, respectively. It is observable that among all the line VSIs, SI performs better in identifying the bus close to the voltage collapse.

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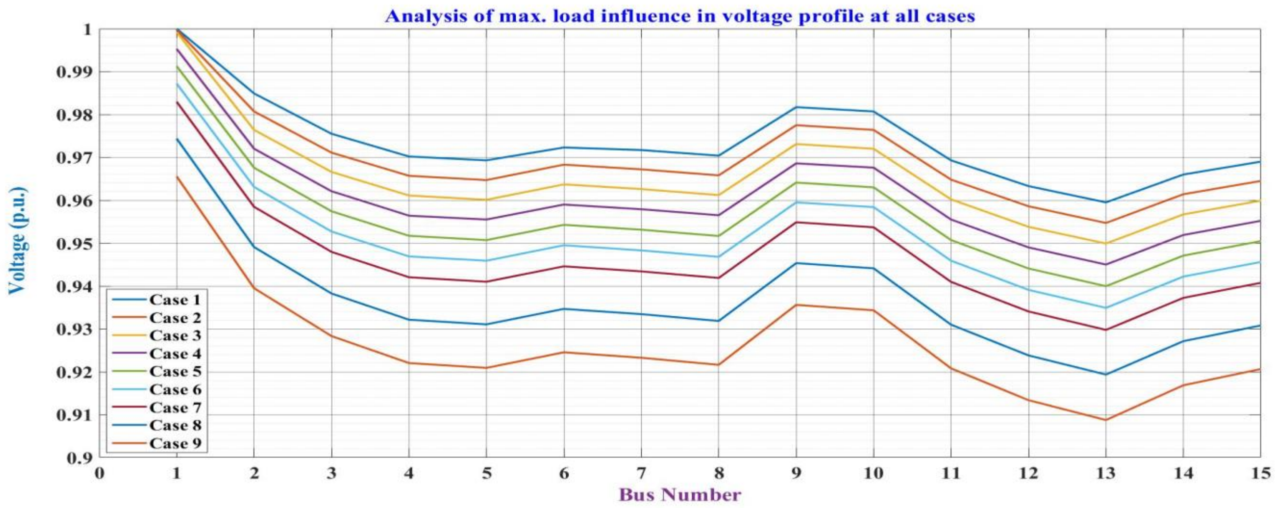

Fig 4.1.1 Analysis of max. load influence in voltage profile in all cases

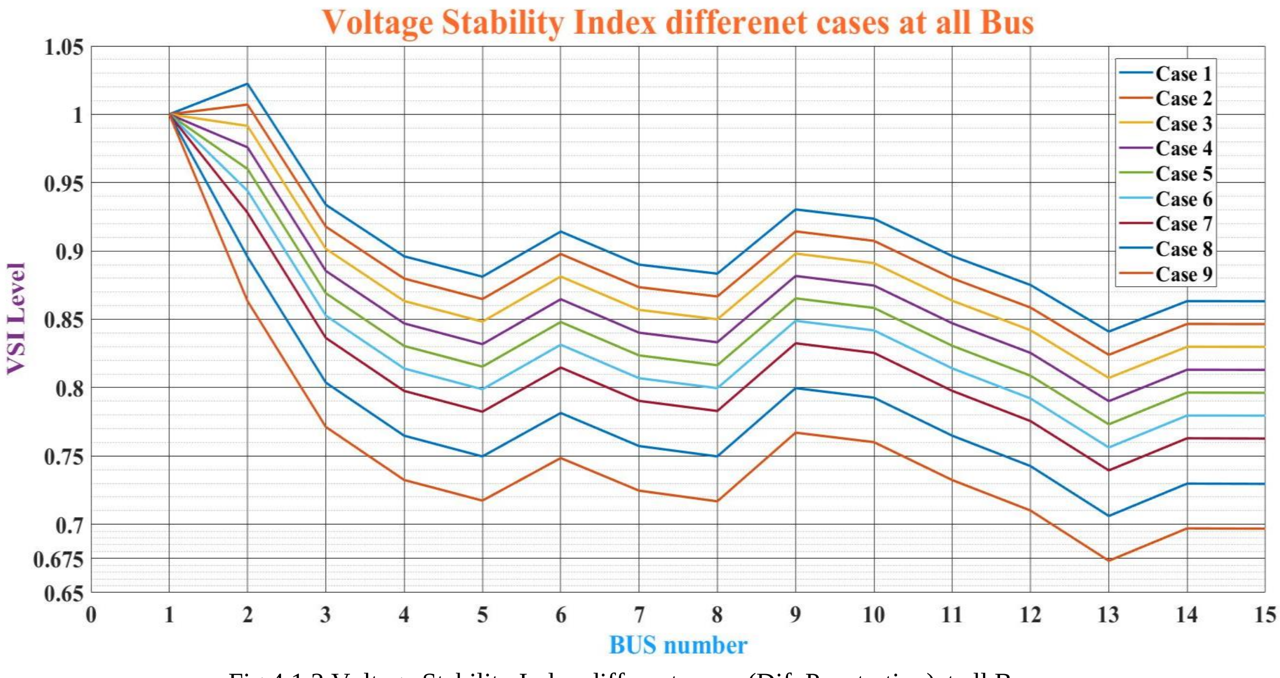

Fig 4.1.2 Voltage Stability Index different cases (Dif. Penetration)at all Bus

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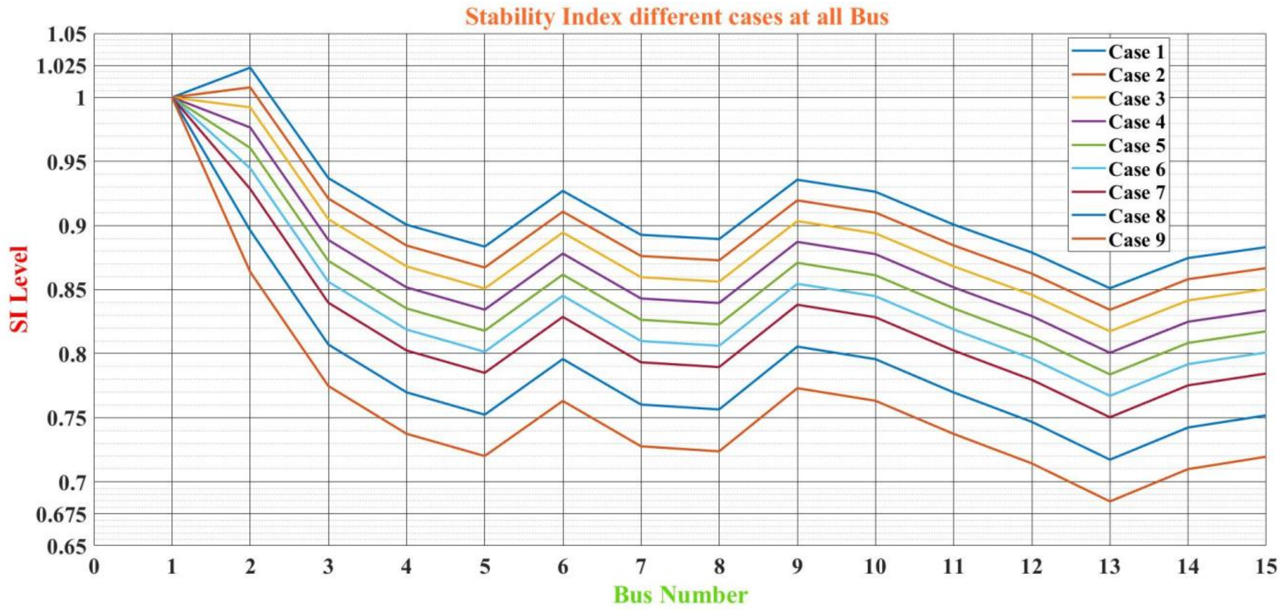

Fig 4.1.3 SI level at all Bus different level penetration load.

The bus with the lowest index value in the system is the weakest in the system. Similar to this, a low bus voltage profile value denotes a bus that is near the voltage collapse. The voltage at bus 13 has the lowest bus voltage, as can be seen in Table 2. The values of the VSI and SI indexes fall within the range of a stable system. Since 13 is the lowest value, the system is unstable. The lowest voltage bus is the weakest bus in the system according to all the indices.

4.2. Assessment of EVs Charging station load on Voltage stability.

On the test systems for the IEEE 15-bus, simulations were conducted. Analysis of the voltage collapse issue was done in consideration of the increasing load. The outcomes were predictable in their nature. According to the findings, VSI and SI were the indexes most useful for locating the test system's weak bus. As a result, the index may be considered a placement recommendation for the charging station.

CASE	DESCRIPTION	Increase in load (kW)	Effected bus
1	Penetration of fast charging station is placed at bus 2.	300	13
2	Max. Penetration fast charging station is placed at bus 2.	650	13
3	Max. Penetration fast charging station is placed at bus 5.	600	5
4	Max. Penetration fast charging station is placed at bus 6.	650	8
5	Max. Penetration fast charging station is placed at bus 7.	600	7
6	Max. A penetration fast charging station is placed on bus 13.	400	13
7	Penetration of the fast charging station is placed at bus 2 and bus 9.	300&350	13
8	Penetration of the fast charging station is placed at bus 13 and bus 14.	500(250each)	13

Case 6 In a single fast charging station was placed at bus 13 representing the weakest bus in the system. Case 2 In a single fast charging station was placed at bus 2 representing the strongest bus in the system. Case 6 In a single fast charging station was placed at bus 13 representing the weakest bus in the system. Case 7 In a fast charging station was placed at bus 2 and 9 represent the strongest and second strongest bus respectively. Case 8 In a fast charging station was placed at bus 13 and 14 represent the weakest and second weakest bus respectively.

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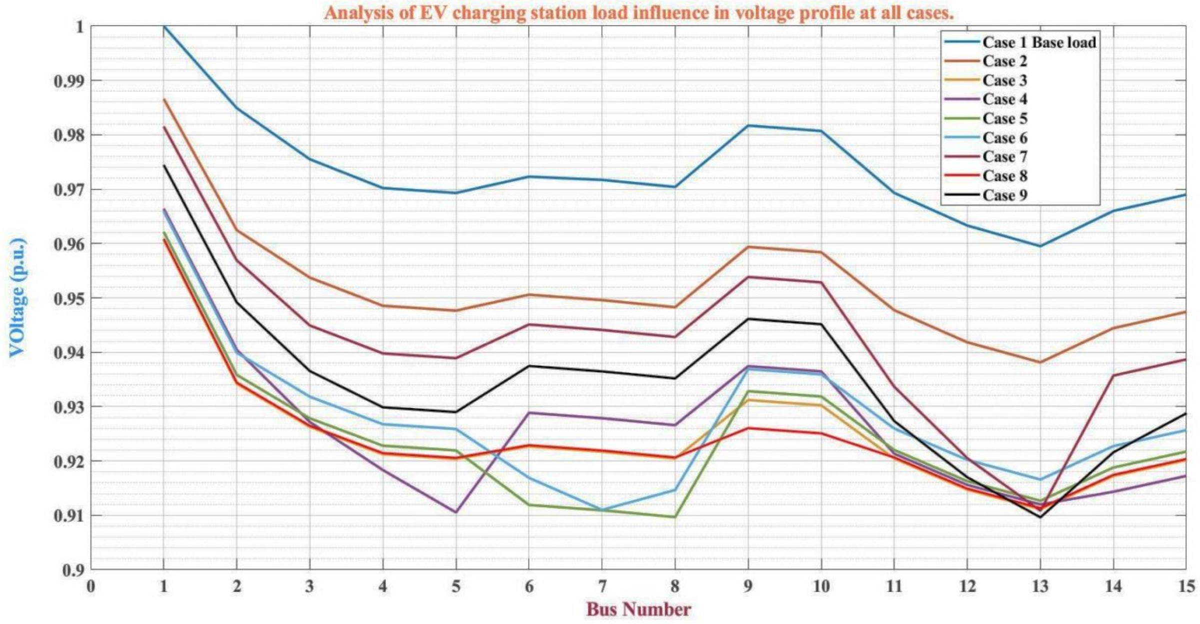

Fig 4.2.1 Analysis of EV charging station load influence in voltage profile in all cases.

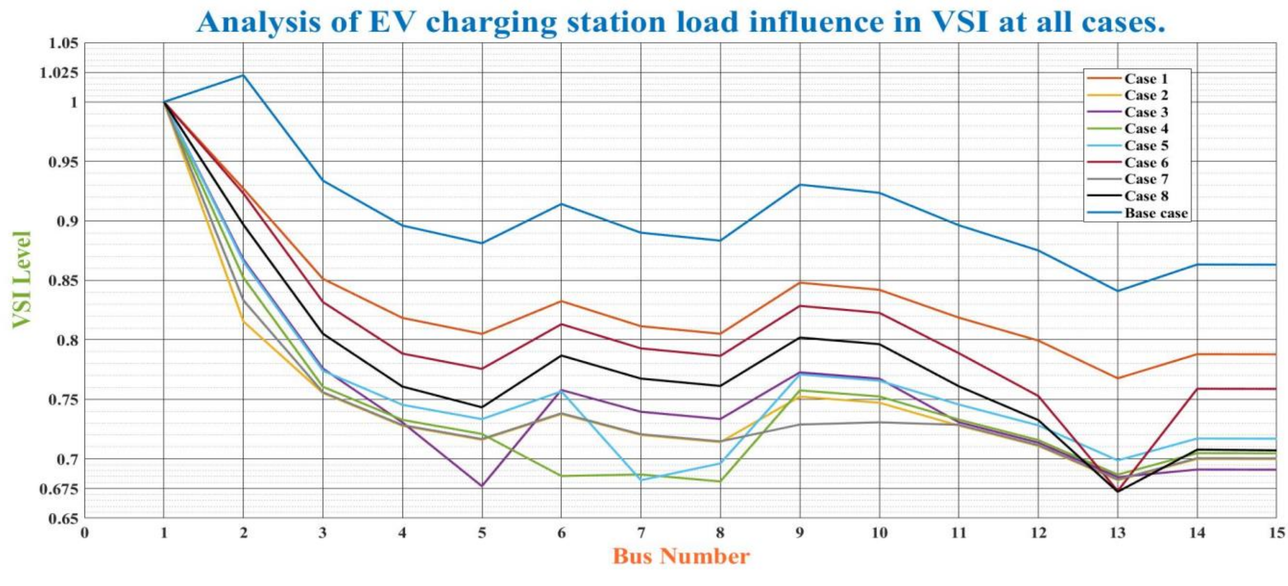

Fig 4.2.2 VSI level at all BUS with Different cases.

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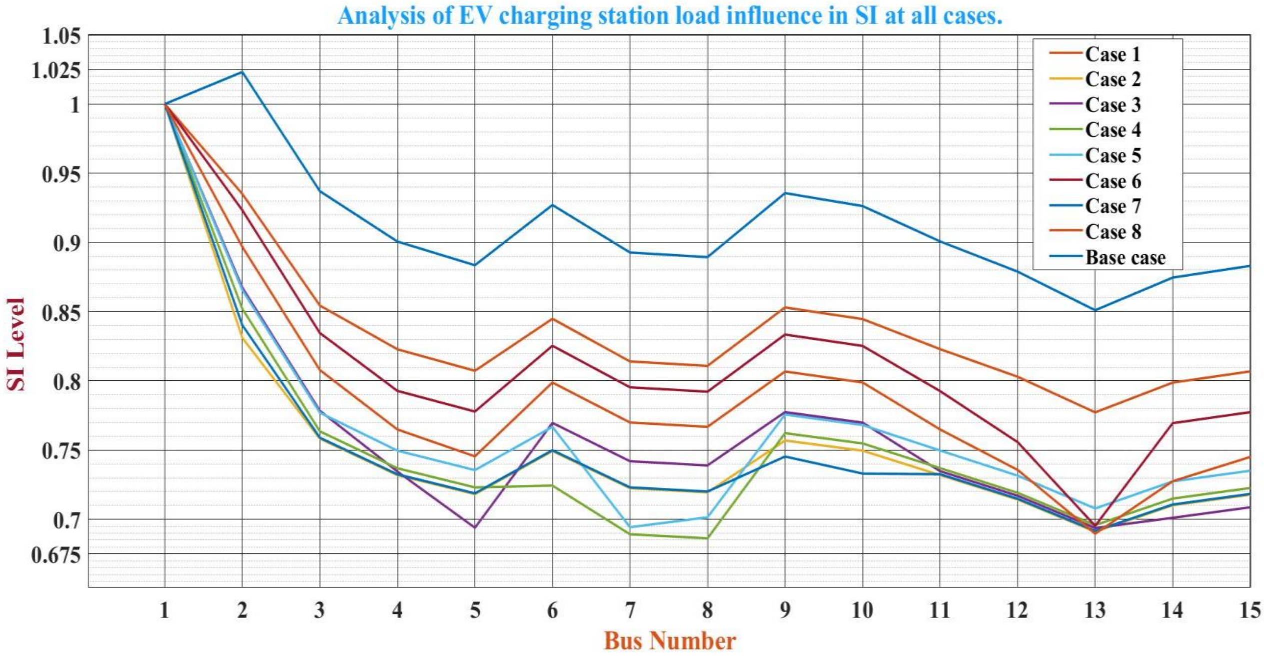

Fig 4.2.3 SI level at all BUS with different cases.

Further, the placement of the charging stations in the distribution network based on an index was proposed in this work. The results obtained indicate the efficiency of the index in finding the most suitable locations for charging stations in the IEEE 15 bus test network.

The effect of EV charging station loads on the voltage stability, reliability, and indices of the IEEE 15 bus test system was carefully examined in this study. The outcomes indicated that installing rapid charging stations at the underpowered buses had an impact on the power distribution network's efficient operation.

5. CONCLUSIONS

In the current days, due to increasing global warming, gas house emissions, and crude oil prices, an electric vehicle is a good option in the transportation sector which replaces the IC engine vehicle. But now due to the growing number of electric vehicles, the increase in charging station load has many effects on the radial distribution system such as loss, voltage problems, load increase, harmonics, stability issues, etc. In it, we evaluated the effects on voltage deviation and voltage stability of the IEEE 15 bus due to an increase in load on each bus. The effects of voltage on increasing the load on the radial distribution system and found the stability of each bus through VSI. In which the voltage limit was allowed up to 0.91 per unit and VSI is 0.69. By increasing different active loads by 5%, 10%, 20%, 25%, 30%, 40%, and 50% at base load on each bus, its effects, and stability index were known. And from that VSI the stability of each bus was known. 13 numbers are the weakest bus and 2 numbers are the strongest bus on RDS. It may be correctly assumed that VSI and SI were the indexes used to identify the weak bus in the test system. Then as given in section 4.2 different cases were performed on IEEE 15 bus and from the base case in the studied IEEE 15 bus, 13 numbers are the weakest bus and 2 numbers are the strongest bus, so with the help of VSI, very good results were obtained. From that, the load of the standard charger of EV on different strongest and weakest buses gave 50kW more penetration. Critical value of VSI is 0.69. So, it can reduce losses, batter voltage profile, maximum loading on system. Further analysis can be done by considering the effects on the voltage of the distribution network and the VSI of each bus.

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