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Optimal Power Flow and Performance Analysis of SPV Penetration to IEEE Bus System Using MI Power

Abstract: - The need to meet changing demand in an economical manner while making the best use of already-expensive electrical systems led to inescapable problems with overloading, increased power transfer coupled with extremely high system loss, and unstable voltage profiles that ultimately resulted in an unreliable system. Power distribution is impacted by the remarkable changes that are currently taking place in the use and provision of energy services. Numerous new avenues for the provision and use of electrical energy have been opened up as a result of developed and diverse distributed technologies, including distributed electricity generation. The emergence of powerful and affordable software has enabled us to cope with the fast-paced development in the power industry which requires updating resources with modern technologies to manage substations. The goal of the proposed work is to integrate solar photovoltaic and optimize the power flow, voltage profile, and real power loss through the building of a simulation model on Mi Power. Power flow analysis was used to calculate the actual power loss, which was then minimized through SPV placement. Additionally, the impact of PV penetration on single bus loading was assessed for all load buses operating in succession with either active, reactive, or combined active and reactive loads.

Keywords: Real Power Loss, Solar photovoltaic, MI Power, Power flow, loading

I. INTRODUCTION

Maintaining and monitoring voltage values within predetermined ranges is essential in any power system as it maintains the system's resilience to disturbances, prevents damage to electrical equipment, and brings down transmission loss. A key determinant in an electrical transmission system's ability to operate reliably and increase the effectiveness of real power transfer to customers is the quantity of reactive power supplied to the system. Voltage collapse is brought onby an insufficient reactive power supply which ends up in system instability. The voltage profile of the network will deteriorate when the supply of reactive power decreases, and the system voltage will rise as it increases. Due to a lack of available reactive power, the voltage must be raised to sustain the power supplied by decreasing the voltage and raising the current. As a result, there is a decrease in voltage and an increase in reactive power consumption. If the current continues to rise,the transmission line will trip, overloading more lines and leading to cascading failures.

If the voltage value continues to drop, other associated elements trip, causing the voltage to drop even more. The planning process, as well as the expansion or modernization of transmission and producing facilities without overloading the existing lines, are impacted by performing analysis of the power flowing in the system. Additionally, its output can be applied to stability analysis, optimal dispatching, and contingency analysis. As the power business develops quickly,it is necessary to update resources with cutting-edge technology in order to operate substations. This has been made possible by the development of strong and reasonably priced software. Utilizing cutting-edge advanced simulation software that aids in replicating the dynamic behavior of the system, there is a pressing need to establish intricate connections with the industries in orderto provide a thorough understanding of the current conditions. In order to perform LFA (Load flow analysis), a variety of computational tools are employed, including MATLAB, Mi POWER, the Power analysis toolkit (PAT), and Sim Power Systems (SPS). Mi Power is a highly dynamic, user-friendly toolkit for stability and steady-state analysis of power systems, including dependability and protection. It is a Windows-based application. The development of renewable energy sources has presented new difficulties for the vertically arranged electrical system. To make the current network more capable, power engineers are constantly working on new technologies. In order to switch to cleaner energy, renewable energy sources are essential. One of the

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main elements [1] that maintains the average temperature increase below 1.5°C is the use of renewable energy, and in the global production of electricity, the share of renewable energy increased to 29% in 2020 from 27% in 2019.

The suggested work analyzes power flows to assess the performance of standard IEEE test bus systems with renewable energy integration. The load flow is performed using Newton Raphson approach, and a load flow model is created in Mi Power software for analysis. The analysis was carried out with the goal of evaluating the performance characteristics such as voltage, active and reactive power, and line flows in a system with the given loading state. The standard IEEE5 Bus test system was employed and modified by connecting the grid via RES penetration.

The remaining paper is organized as follows, Section 1 introduces the problem. Section 2 reviews the relevant literature. Section 3 describes the mode of operation of the problem. Section 4 presents the IEEE-5 Bus data sheet and analyzes the results and Section 5 concludes the paper.

II. LITERATURE SURVEY

Renewable energy accounts for 26.53% of the country's gross installed generating capacity in India. Globally, it is now ranked fourth in terms of total installed renewable energy capacity. The capacity of solar energy has grown from 2.6 GW to more than 46 GW. Recent developments have resulted in lower RES costs. SPV and wind energy contribute to overall power generation globally. The authors [2] emphasized that designing new installations and determining optimal operating conditions for existing systems necessitates an analysis of power flowing through the system while also maintaining the cost/benefit ratio for both the demand and supply sides.

The authors of [3] observed that the grid supply was unreliable, and that with rising power prices, it was vital to integrate RES such as solar into the system. In [4] a novel approach for analyzing transformer states in load flow studies was proposed, taking into account the limits of the transformer state and the control and testing it on the IEEE 300 bus system.

The time series evolution of the conditional number of Jacobian matrices in [5] was performed to detect weak nodes and validated in the New England 39 bus test system, proving that the methodology efficiently identified the critical bus. The authors of [6] simulated a 132/11 kV distribution substation with variable load from one hour to the next, resulting in unacceptable voltage fluctuations.

In [7] a unique planning technique was developed to reduce total operating cost and active power loss by optimizing the placement of FACTS devices to adjust for the VARs flowing across the line. The authors of [8] emphasized the necessity of FACTS devices in dealing with difficulties of renewable energy penetration into existing systems. Power engineers are familiar with optimization as a solution. Globally, extensive research has been conducted to determine the best location for STATCOM.

III. MODE OF OPERATION

3.1 Power flow analysis

It is a numerical analysis of the flow of power in a network. It provides the system's steady- state performance under any load condition. When planning a new project or expanding an existing network, it is crucial to make the system stable by maintaining voltage and current limits. The NR approach is used to evaluate the performance parameters in this paper.

3.2 Identification of weak nodes and lines

Selecting proper locations for additional VAR sources or distributed energy generation helps to improve the efficiency of the power transmission system. The actual choice of the weak nodes or lines aids in the unnecessary use of FACTS devices owing to their high installation cost. The weak nodes or lines are identified as the most exposed ones with respect to unstable voltage profiles or disturbed flow of VARs. The locations are determined as a result of mathematical calculations.

3.3 Optimal placement of SPV

SPV integration into the existing grid contributes to more sustainable, more flexible energy with net zero carbon emissions. Because there are no moving parts, it requires minimal maintenance. Before connecting the SPV to the existing grid, the best site must be chosen in order to achieve better outcomes with lower running costs and higher dependability.

IV. SYSTEM DEVELOPMENT AND PERFORMANCE ANALYSIS

The suggested approach has been validated using IEEE 5 Bus network data. Two generators, three load buses, and seven transmission lines make up the basic test system. The following parameters are taken into account: a base MVA of 100 MVA, a base frequency of 60 Hz, and a base kV of 220 kV.

4.1 Steady State Power Flow Analysis

The aforementioned test system's steady-state power flow analysis was performed on the MiPower platform. Figure 1 shows the Simulink model of a typical IEEE 5 Bus system.

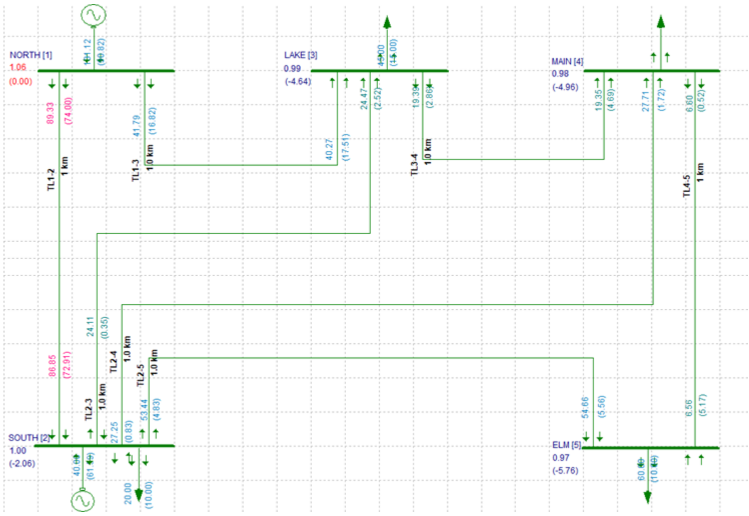

Figure 1 IEEE 5 bus test system Simulink model on Mi Power

The voltage profile and power flows are illustrated in Figs. 2 and 3. Owing to its fast convergence and precise results, Newton Raphson's approach is used to perform load flow analysis in the proposed study.

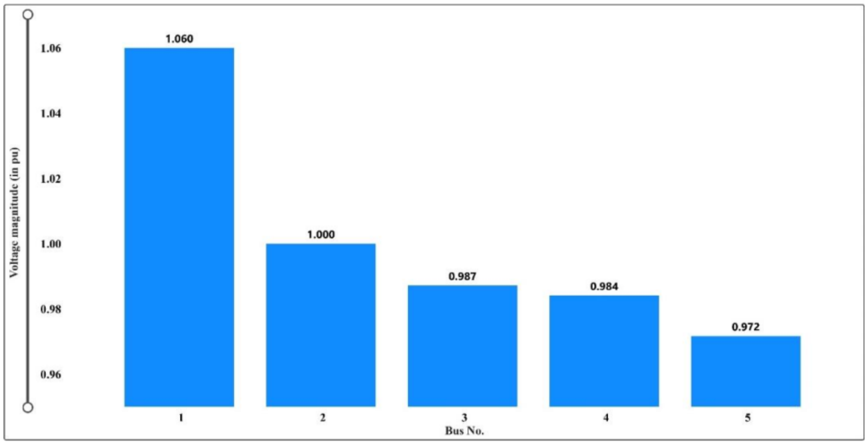

Figure 2. Voltage magnitude after load flow

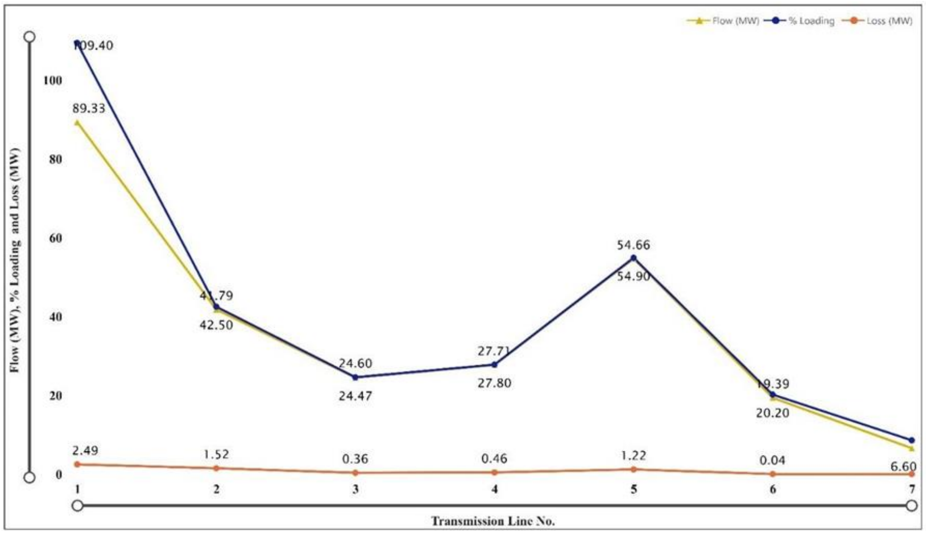

Figure 3. Line losses after load flow

In the original test scenario, Bus 1 exceeded both the maximum voltage and the maximum Q limits, but Bus 2 exceeded only the minimum Q restriction. Line 1 was fully loaded, whilst lines3, 6, and 7 were just partially laden. The overall active power generated was 171.122 MW, while the total VARs generated was 29.223 MVAr. The whole real power loss was 6.1222 MW, or3.578%.

4.2 Identification of Weak/Critical Nodes

The load values were now increased in steps of 5% up to 40%, and a load flow study was performed. Table 1 displays data for variations in voltage magnitude in pu across all buses. The average voltage change is compared to the original standard test case result. The bus with the highest discrepancy between the original standard test scenario and the average is considered themost vulnerable node. Based on Table 1, it is possible to deduce that bus no. 5 is the critical node.

Table 1. Critical node identification

Bus No.	0%	5%	10%	15%	20%	25%	30%	35%	40%	Average	Difference
1	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	0
2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1	0
3	0.99	0.98	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.982	0.0026
4	0.98	0.98	0.99	0.98	0.98	0.98	0.98	0.98	0.98	0.979	0.0042
5	0.97	0.96	0.96	0.97	0.97	0.97	0.97	0.97	0.97	0.969	0.0051

4.3 Optimal Placement of SPV

SPV was installed at the indicated critical node, bus 5, and a load flow study was done. Figure4 depicts the simulation model after PV placement. Figures 5 and 6 show the voltage profile and power flow, respectively. Three cases are examined here for testing purposes:

Case 1: A PV facility with a capacity of 2 MW.Case 2: A PV facility with a capacity of 5 MW.Case 3: A PV facility with a capacity of 10 MW.

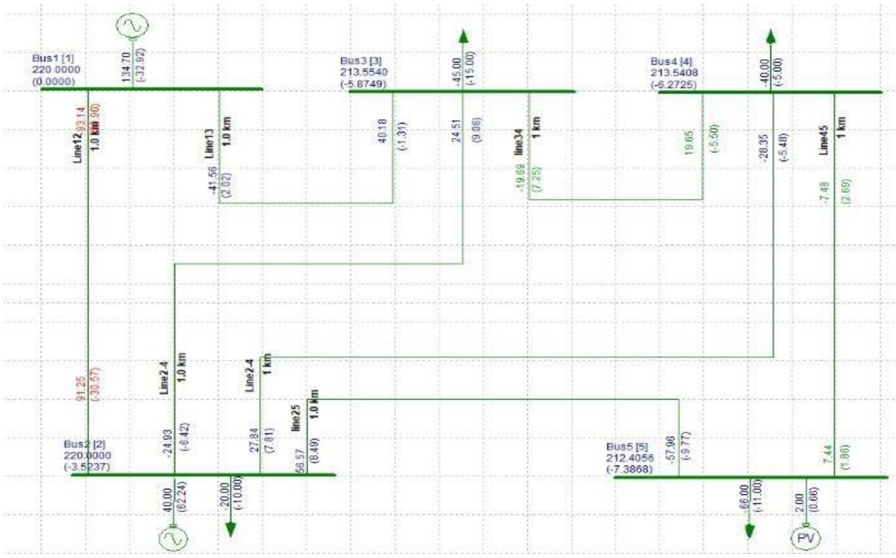

Figure. 4 Simulink model of the IEEE 5 bus test system with SPV at bus 5 on Mi Power

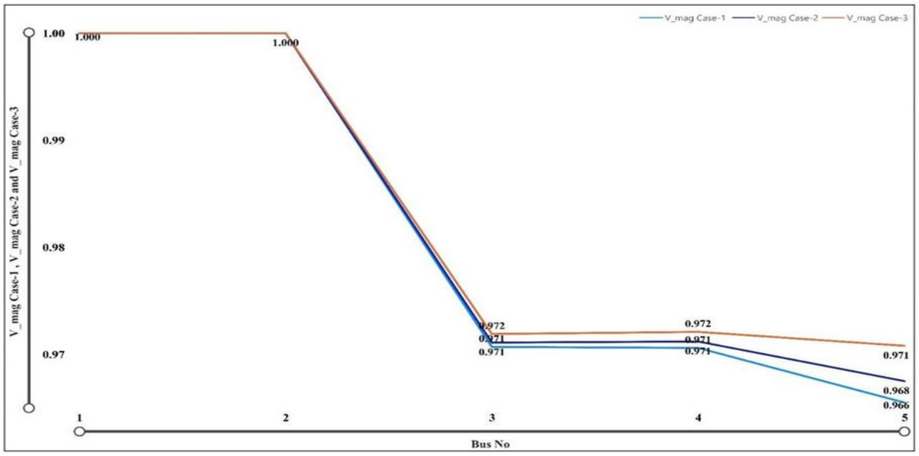

Figure 5 Voltage magnitude of all buses upon SPV connection at Bus 5

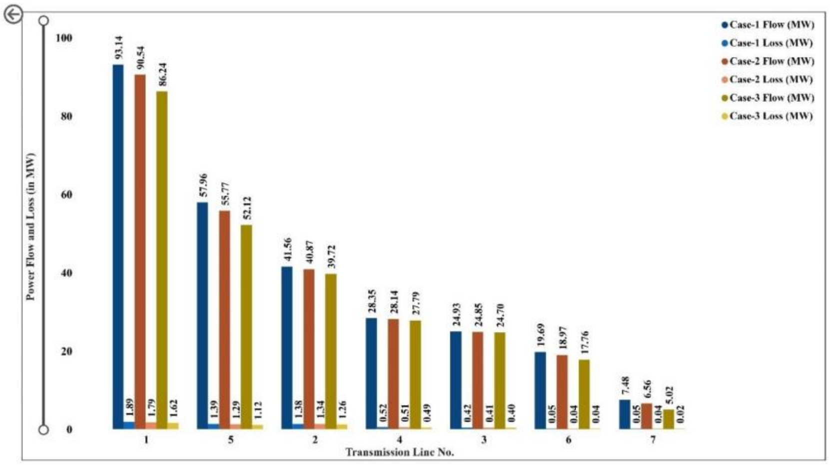

Figure 6 Line losses following load flow post SPV connection at Bus 5

After PV deployment, Bus 1 surpassed the minimum Q limit, and transmission line 1 was loaded above 100%, whilst the remaining lines were loaded below 65% in all three situations mentioned above. Table 2 shows the overall power generation and percentage losses of the system.

Table 2. Total generated power and percentage losses at Bus 5 resulting from PV penetration

Parameters	Case 1	Case 2	Case 3
Percentage Real Loss (AC + DC)	3.22	3.07	2.82
Total Reactive Power Generation (Conventional) (MVAR)	29.33	27.46	24.42
Total Real Power Generation (Conventional) (MW)	174.69	171.41	165.96

4.5 Single bus loading using Watts, VARs, or aggregated loads for all load buses in series.

Three situations are considered here for testing purposes. Figures 7–12 detail the voltage profile, whereas Figures 13–18 depict the MW loss for the three situations discussed above.

Case 1: The MW and MVARs are both adjusted in the same proportion.

Case 2: When the MW is increased but the MVARs remain constant. Case 3: When the MVAR is increased while the MW is held constant.

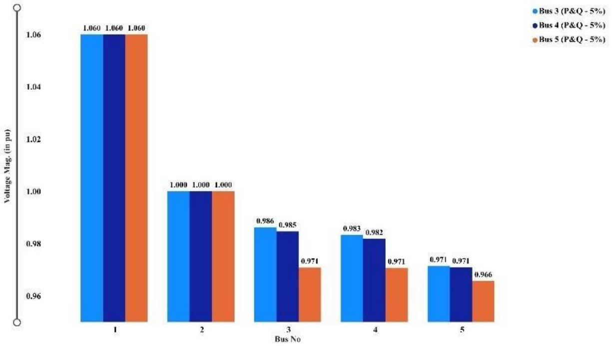

Figure. 7 Voltage magnitude of all buses for case 1 (5%)

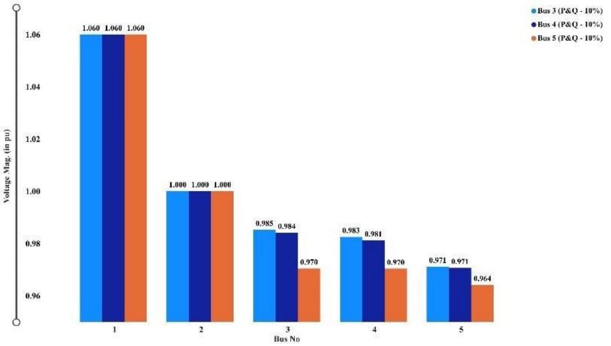

Figure. 8 Voltage magnitude of all buses for case 1 (10%)

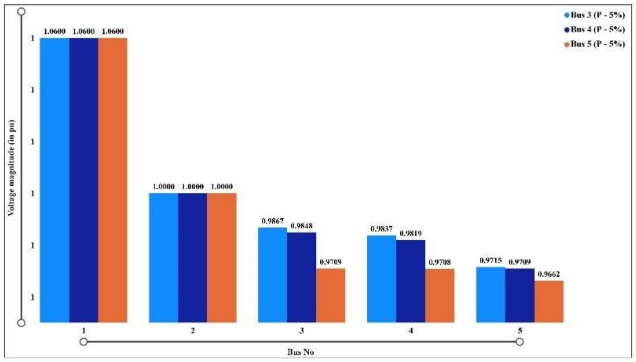

Figure 9 Voltage magnitude of all buses for case 2 (5 %)

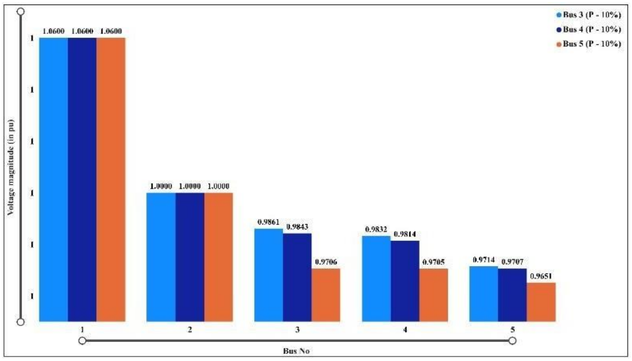

Figure. 10 Voltage magnitude of all buses for case 2 (10 %)

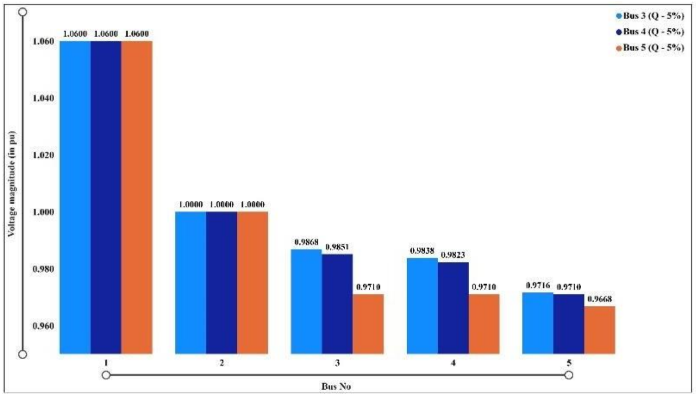

Figure 11 Voltage magnitude of all buses for case 3 (5 %)

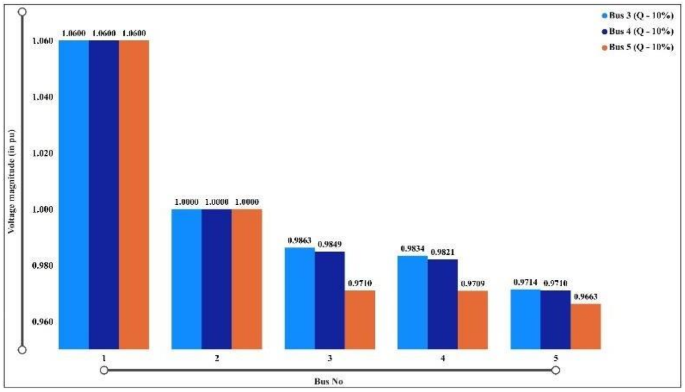

Figure 12 Voltage magnitude of all buses for case 3 (10 %)

On increasing the loading of the buses for all load buses sequentially with either active, reactive, or both active and reactive loads it was observed that the summation of all the transmission lines' power flow loss connected to Bus 5 decreases but the voltage profile of the busis on the verge of instability as compared to other buses.

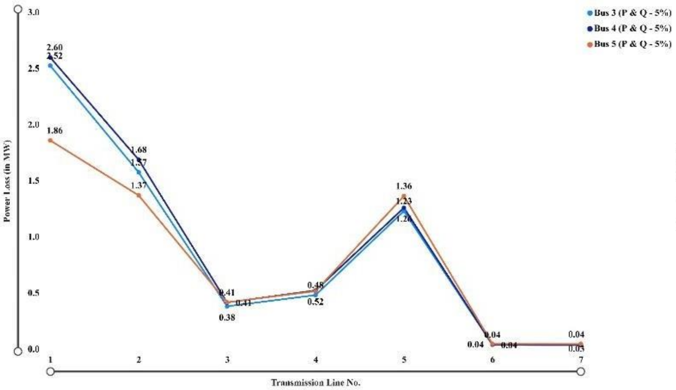

Figure.13 Line losses in case 1 (5%)

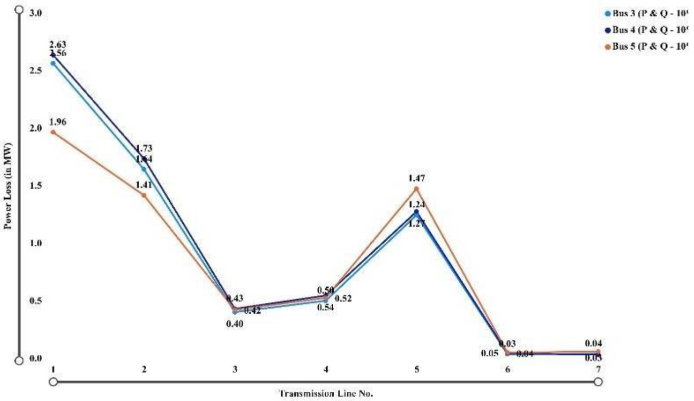

Figure.14 Line losses in case 1 (10%)

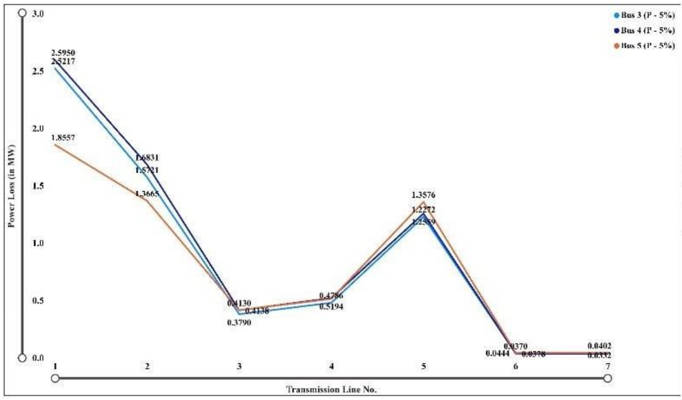

Figure.15 Line losses in case 2 (5%)

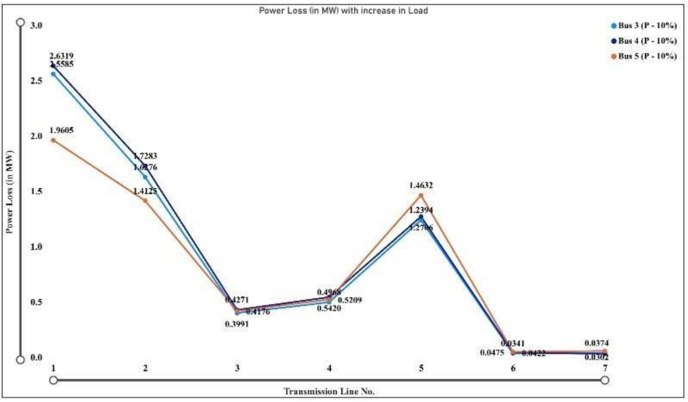

Figure.16 Line losses in case 2 (10%)

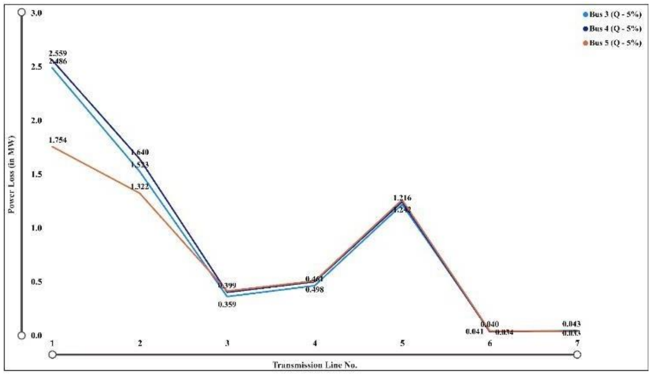

Figure.17 Line losses in case 3 (5%)

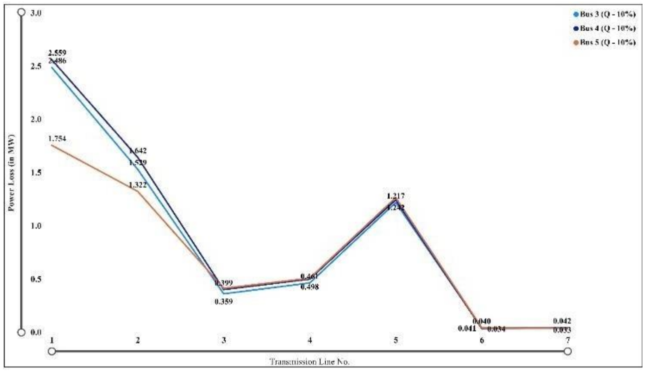

Figure.18 Line losses in case 3 (10%)

4.6 Impact of PV penetration on a single Bus Loading all load buses in order with active,reactive, or mixed power loads.

PV penetration was increased in all of the scenarios evaluated in section 4.5. Figure 19 depicts the overall active power losses. When the load increases, increased SPV penetration contributes to a reduction in total actual power loss. Increased SPV penetration and rise in the active load component resulted in a decrease in loss but not that much as compared to the former case. However, increasing SPV penetration and considering the reactive load component resulted in a reduction in loss, indicating that variations in reactive power load have an important effect on overall system loss.

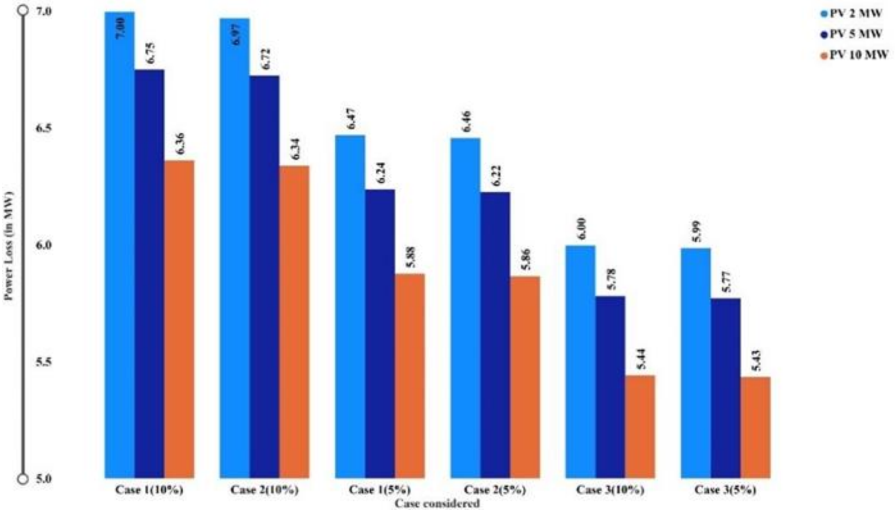

Figure 21 Total real power loss

V. CONCLUSION

The steady-state behavior of the IEEE 5 Bus system with and without SPV penetration was investigated under various loading circumstances. Weak nodes in the system were detected, and the best position for the SPV was discovered. The effectiveness of RES penetration, such as SPV,has been investigated. The increased penetration of RES in the grid reduces line losses as well as total actual power generation (Conventional) and total reactive power generation (Conventional). Furthermore, single bus loading for all load buses done in sequence with either Active, reactive or power loads revealed that while Bus 5's total active power loss decreases, its voltage profile is on the verge of instability when compared to other buses. Also, with the increase in SPV penetration and increase in only the active load component resulted in a decrease in loss but did not have much difference when compared to the increase in total load. But the increase in SPV penetration and only the reactive load component resulted in a decrease in loss thus indicating that the change in reactive power load has a prominent effect on overall system loss.

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