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Optimal Sizing of Distributed Generation for Distribution System with Reliability and Cost Analysis

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ABSTRACT

Distribution system plays an important role in the power system as it is common point for both bulk power and consumers. So, it is necessary to provide the proper power to the customers with increasing demand in the power supply. Distributed Generation (DG) is a one which generates the power in small-scale and it is placed nearer to the load to reduce the transmission losses. Due to importance of the fossil fuel, the electric vehicles are starts to develop in large manner. So, for charging these electric vehicles, the Charging Station (CS) is newly added to the distribution system. So, the pressure in the generation system is increased which may reduce the reliability of the selected network. The optimal location for the placement of CS and DG is done using Loss Sensitivity Factor technique. The size of the distributed generation is calculated by Particle Swarm Optimization technique. The reliability is compared between the system integrated only with CS and the system integrated with DG as well as CS. And the cost requirement for the implementing the distributed generation is analysed. This proposed method is analysed by using MATLAB simulation.

Keywords: Reliability analysis, Particle Swarm Optimization, Electric Vehichle, Distribution generation, Distributed System.

I. INRODUCTION

The power system consists of three major units namely generation, transmission and distribution units. The Generation unit is to generate the electrical power(11-25kv) and then it is stepped up using transformer and this power is transmitted to distribution station via transmission lines. Distribution system is one of the main sections in the power system as it is common point for both bulk power and consumers [1,2]. Now-a-days the demand for the electricity has been increasing in the huge manner. So, it is very essential to provide the proper power without any interruption. It is important to maintain the reliability, power quality, efficiency of the system. The main source for the fuel of is fossil fuel. The demand for the fossil fuel is increasing in large manner [3,4]. So, the Alternate solution for this problem is electric vehicles. Due to importance of the fossil fuel, the electric vehicles are starts to develop in large manner. PHEV is integrated in the distribution network where the load is increased in the distribution system.

The Electric vehicles are of three major types. Battery Electric vehicle (BEV) and Plug-in Hybrid Electric vehicle (PHEV) are the types of Electric vehicles. PHEV is working on the same principle as like as the Hybrid Electric vehicle and this battery is charged through the external power [5]. This can be done by plugging in with the Charging Station (CS). So, by using the electrical energy as the fuel for the vehicles, the usage of fossil fuel can be reduced and hazardous gas emission from the vehicles is also reduced. This electric vehicle is helps to save the decreasing fossil fuel rate and eliminates the hazardous gas emission. For the electric vehicles, the CS is new to integrate into the system. So, while introducing the substation stress is increased in huge manner and the new load into the system will automatically increases the losses and the reliability of the system is decreases, as voltage drops [6]. The reliability of the system can be increased by introducing the DG in the distribution unit.

DG is a one which generates the power in small-scale and it is placed nearer to the load to reduce the transmission losses. The losses in the transmission unit are reduced as the DG is located close to the load side [7,8]. Due to decreasing of the fossil fuel rate, the electric vehicles are starts to develop in large manner. For charging these vehicles, the CS is newly added to the distribution system. So, the pressure in the generation system is increased which may reduce the reliability of the system. The Optimal sizing of the DG can be analysed using the Particle Swarm Optimization technique [9]. And the load flow analysis for the distribution system can be calculated by using the Backward and Forward sweep algorithms. With the help of this algorithm, the proper placement of the DG and CS can be analysed. The integration of DG in the distribution system will helps to increases the performance and reliability of the distribution network [10].

It is very essential to maintain the reliability of the system in the proper manner. So, For the reliability analysis, there are lot of methods are available to calculate the reliability of the system and the System Average Interruption Duration Index is one of the indexes which is used to analysis the reliability of the Selected network [11,12]. The reliability is compared after integrating the DG into the selected network. The type of Distribution Generation can be renewable or non-renewable source. The renewable energy source can be selected for Distribution Generation because to reduce the effect on environment by Generating station [13,14]. The cost is also analysed for integrating the DG in the distribution network.

Based on the performed literature survey, the objective of the paper is formulated as

- To determine the optimal location for DG using loss sensitivity factor and estimate the optimal size of DG using Particle Swarm Optimization (PSO).

- Evaluation of reliability in the distribution System by using System Average Interruption Duration Index (SAIDI).
- Estimation of cost required for the Distributed generation (DG).

III. PROBLEM FORMULATION:

Load flow analysis

Considering the distribution line segment connected between two nodes i and j shown in Figure 1, the Loss Sensitivity Factor is calculated as follows,

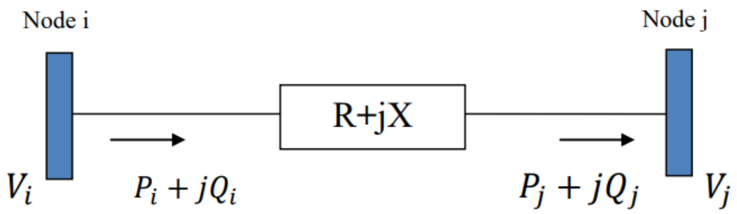

Figure 1 Distribution line segment connected between two nodes

The current through node i and node j is calculated as below,

$$|I_i|^2 = \frac{(P_i^2+Q_i^2)}{V_i} \quad (1)$$

$$|I_j|^2 = \frac{(P_j^2+Q_j^2)}{V_j^2} \quad (2)$$

Where,

$P_i$is active power ; Q_i is reactive power at node i.

P_j is active power ; Q_j is reactive power at node j.

V_i and V_j are voltages at node i and j.

The P_{loss} and Q_{loss} are showed in terms of the current flowing in the line as follows:

$$P_{loss} = \left(\frac{P_j^2+Q_j^2}{V_j^2}\right) R \quad (3)$$

$$Q_{loss} = \left(\frac{P_j^2 + Q_j^2}{V_j^2}\right) X \quad (4)$$

The problem formulation for minimizing the loss in the distribution system for N-bus is given below

$$P_L = \sum_{k=1}^{n} Loss_k \quad (5)$$

Where, $Loss_k$ = Loss in the k-th branch

n= total no. of buses.

P_L =Power loss in distribution system.

Loss sensitivity factor(LSF)

The LSF is calculated by the below equation. The loss sensitivity factorsfor all the buses from load flows are calculated.

$$\frac{\partial PL}{\partial Q} = \frac{(2 \times Q(j)) \times R_k}{V(j)^2} \quad (6)$$

System Average Interruption Duration Index (SAIDI)

SAIDI is a reliability index and it is calculated as follows,

$$\text{SAIDI} = \frac{\sum U_i N_i}{N_T} \quad (9)$$

Where,

N_i - is number of customers interrupted in the system

U_i - is duration of interruption in the system

N_T - is total number customers in the system

IV. METHODOLOGY:

Algorithm

Step 1: The distribution system model is selected.

Step 2: For the selected system bus data is collected.

Step 3: For the selected system line data is collected.

Step 4: Load flow analysis is performed for the selected system with the collected data. Backward-forward sweep algorithm is used for load flow analysis.

Step 5: The voltage, real power for each bus, reactive power for each bus, real power losses, reactive power losses are evaluated by load flow analysis.

Step 6: The optimal location or place of Charging Station to be integrated is found by Loss Sensitivity Factor.

Step 7: Based on the value of LSF and normalized voltage, the location is determined. The CS is integrated in the distribution system where the LSF value is minimum and normalized voltage is less than 1.01v.

Step 8: Again, load flow analysis is performed to find the losses for the new system. The optimal location of DG is also determined by LSF to minimize the loss occurred in the system.

Step 9: Based on the value of LSF and normalized voltage, the location is determined. The DG is integrated in the distribution system where the LSF value is maximum and normalized voltage is less than 1.01v.

Step 10: The optimal size of DG is calculated by using Particle Swarm Optimization technique.

Step 11: The reliability of the system is assessed based on SAIDI value. Reliability is assessed for 24 hours for the system with CS and with both CS and DG.

Step 12: The cost for Distribution Generation Renewable energy is analysed.

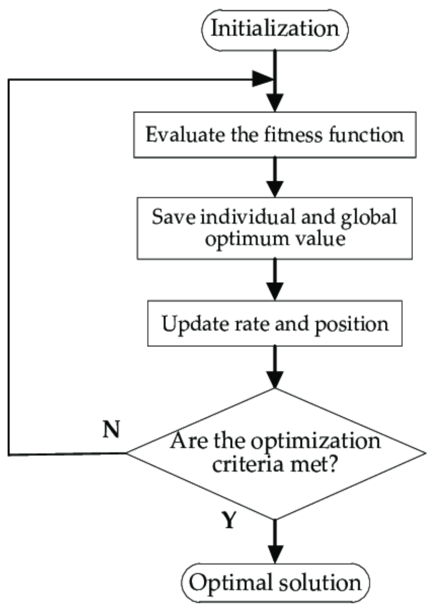

Figure 2 Flowchart of PSO

V. RESULT AND DISCUSSION:

IEEE 12 bus radial distribution system

The 12 bus radial distribution system is used to analyze the methods. The Figure 3 shows 12 bus system. It consists of 11 load buses connected via single main feeder. The bus data and load data for the 12-bus system is collected. The real and reactive power required for the system is 435 kW and 405kW. The load flow analysis is analysed to calculate the real and reactive power losses for each bus is calculated. The real and reactive power supplied from the substation is 455.7138 kW and 413.0411 kW. The total real and reactive power loss is 20.7138 kW and 8.0411 kW, respectively.

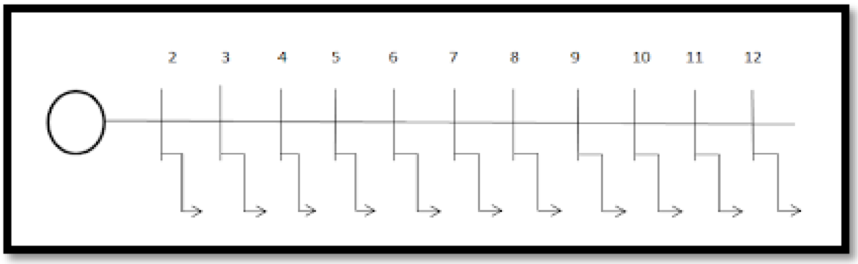

Figure 3 12 Bus System

Integration of charging station

The CS is to be integrated to the system. The location for the CS is identified by Loss Sensitivity Factor to reduce the losses in the selected network. The LSF and normalized voltage for each bus is calculated. The CS should be integrated at the bus which have minimum value of LSF where normalized voltage is less than 1.01v.

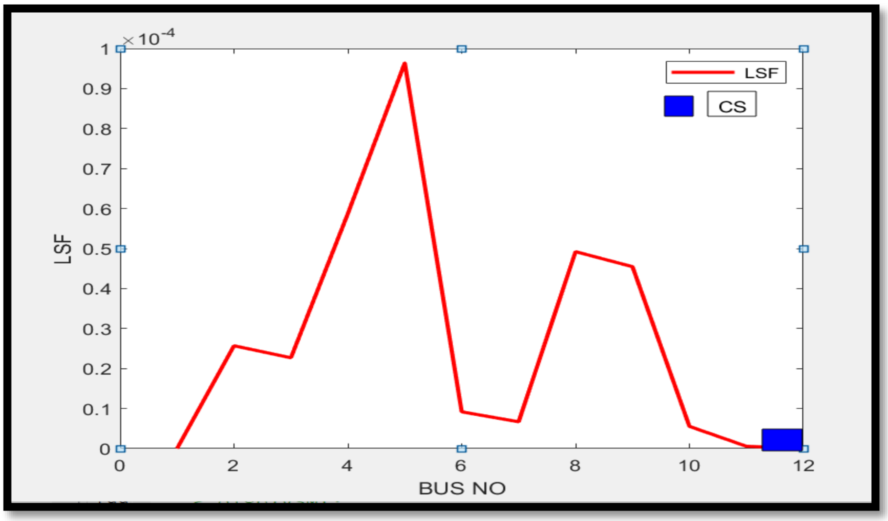

Figure 4 LSF graph with CS

The above Figure 4 shows the LSF value at each bus. The LSF and normalized voltage is compared at each bus. The location for placing Charging Station is found as 12th bus because, the LSF value is minimum and normalized voltage is less than 1.01v.

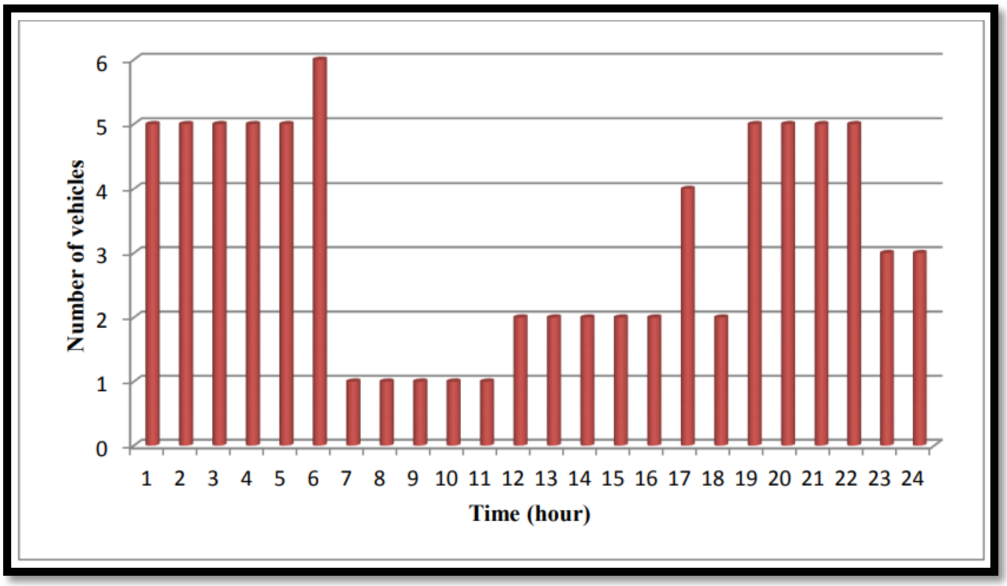

Figure 5 Load Variation Graph

The above Figure 5 shows the load variation in Charging Station for 24 hours. The time for full charge of Hyundai Kona is 6 hours as it allows to travel 312 Km. The load for every hour is determined by number of vehicles charging in that hour. The number of vehicles charging during peak hours is less, so the load consumption is less. Except the peak hours, the number of vehicles charging is more i.e. the load consumption is high. The CS needs power of 156.8 kW. The new load is added to 12 bus system in 12th bus. The load data is changed by adding the new load. The real and reactive loss is increased by integrating the CS. The load analysis is analysed for the new system with CS.

Integration of DG

The DG is integrated to the system to reduce the loss. The location for the DG is identified by LSF to reduce the loss in the selected network. The Loss Sensitivity Factor and normalized voltage for each bus is calculated. The DG should be integrated at the bus which have maximum value of Loss Sensitivity Factor where normalized voltage is less than 1.01v.

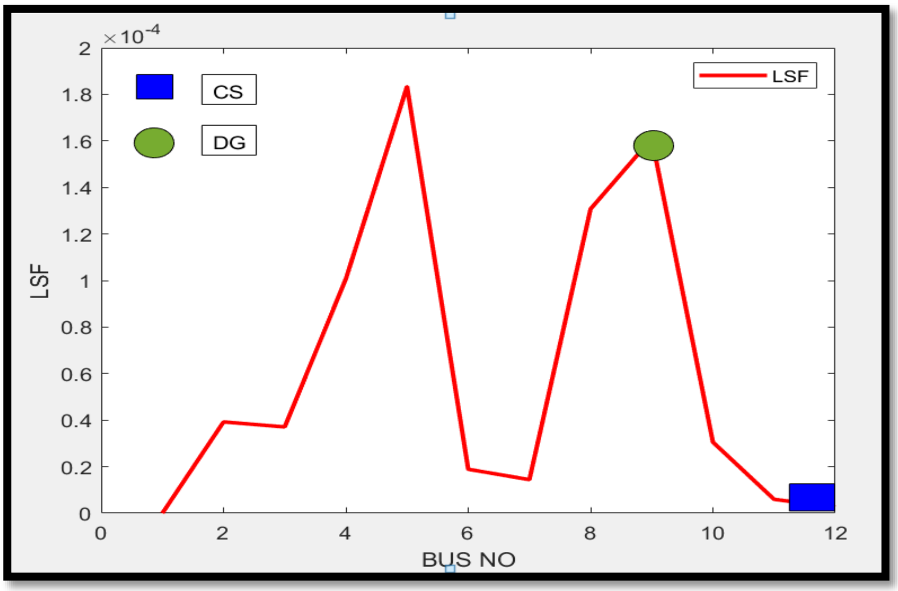

Figure 6 LSF graph with location of CS and DG

The above Figure 6 shows the variation LSF value at each bus. The LSF and normalized voltage is compared at each bus. The DG is placed at 9 bus where the LSF value is maximum and normalized voltage is less than 1.01v.

Size of DG

The location of DG is found. Then the size of DG to be integrated is found by Particle Swarm Optimization technique. The PSO algorithm is simulated in MATLAB for finding the optimal size of DG.

The Figure 7 shows the convergence graph of loss reduced in the system. The size of DG is found to be 394 kW. The real and reactive power loss after integrating both CS and DG is 10.7622 kW and 4.1566 kW respectively.

Performance evaluation

The Figure 8 shows the real power loss at each bus before integrating CS and DG, after integrating CS and after integrating both CS and DG. The real power loss in the system is increased after integration of CS. And it is reduced after integrating the DG at bus 9.

The above Table 1 shows performance analysis of system before integrating CS and DG, after integrating CS and after integrating both CS and DG. After installing charging station, the real power required for the system is increased and real and reactive power also increased. After integrating distributed generation, the real power from the substation is reduced and real and reactive power loss is reduced. The real power and real power loss is reduced after integrating DG in the distribution system.

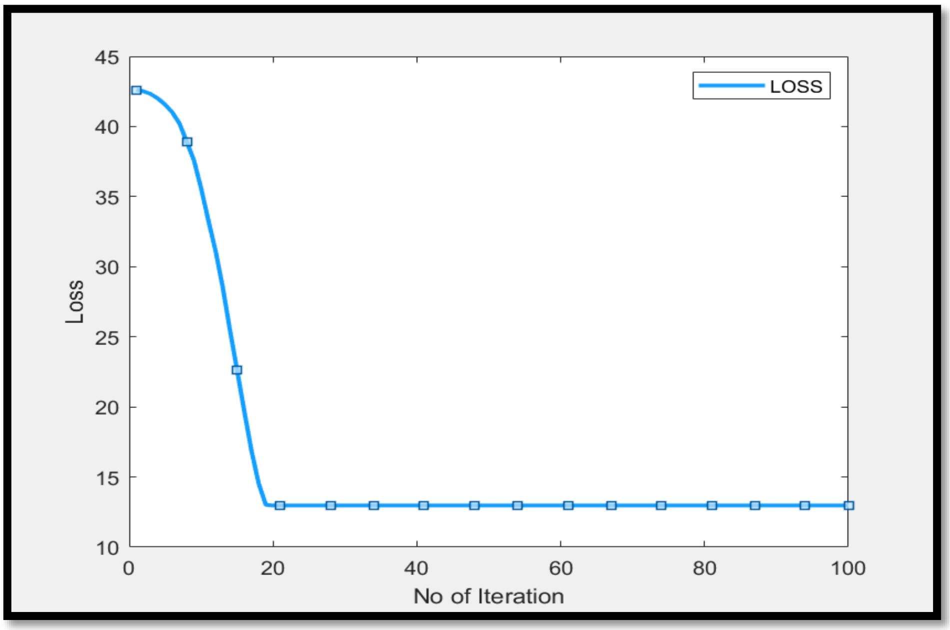

Figure 7 Convergence Graph

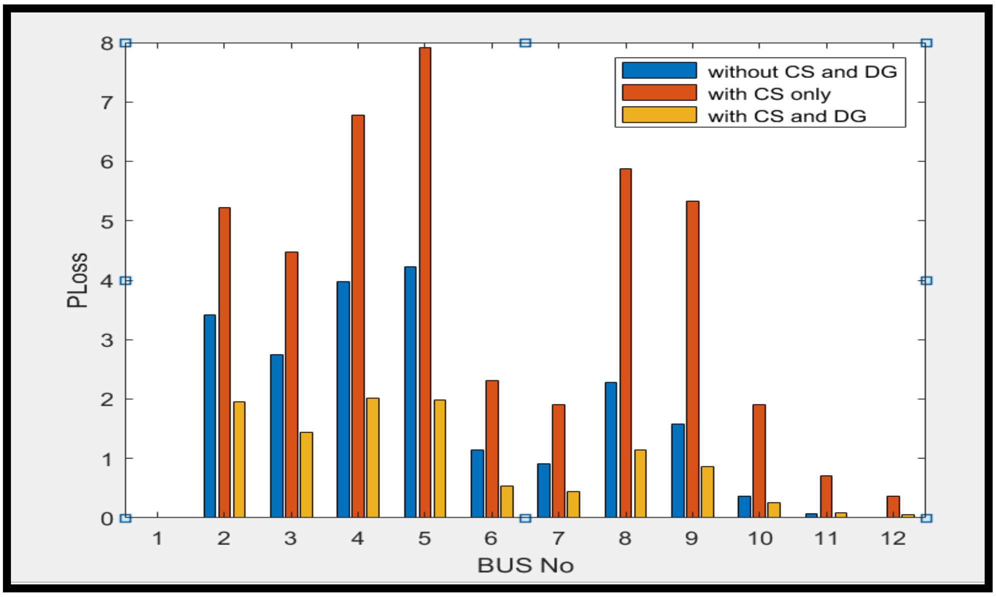

Figure 8 Real Power loss graph

Table 1. Performance Analysis

	Before integrating CS & DG	With CS	After integrating CS & DG
Placement of DG	-	-	9
Size of DG (kW)	-	-	396
Placement of CS	-	1 2	12
Capacity of CS (kW)	-	156.8	156.8
Substation Real Power (kW)	455.7128	632.7734	99.9646
Substation Reactive Power (kVAr)	413.4011	420.8881	409.1566
Power Loss (kW)	20.7138	43.1223	13.0090

Reliability evaluation

The below Figure 9 shows the load profile graph of 12 bus system for 24 hours. The generation capacity of the distribution system is found to be 435 kW. The standard load and Electric Vehicle load for 24 hours is shown in bar graph.

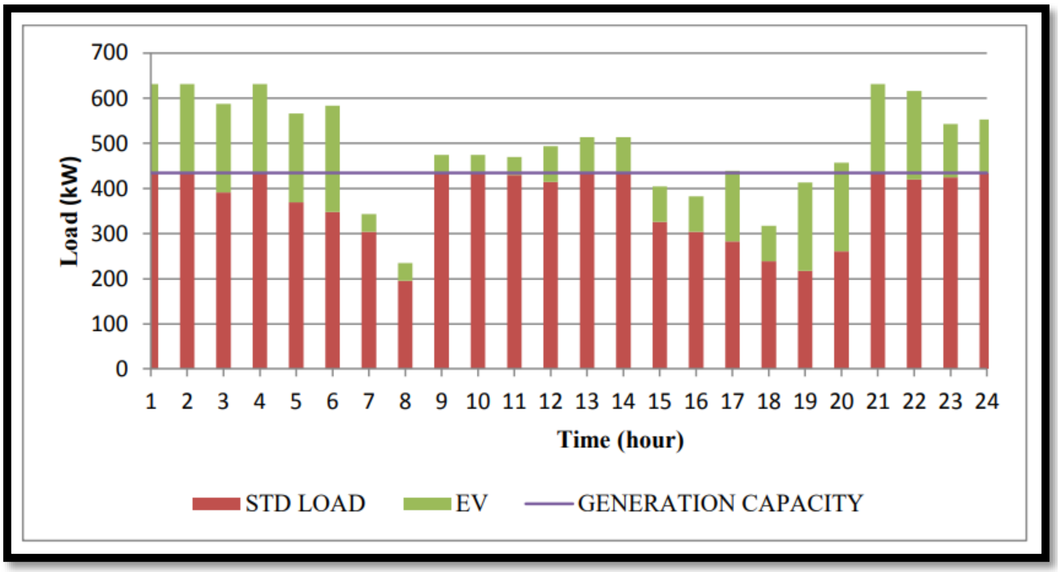

Figure 9 Load profile graph

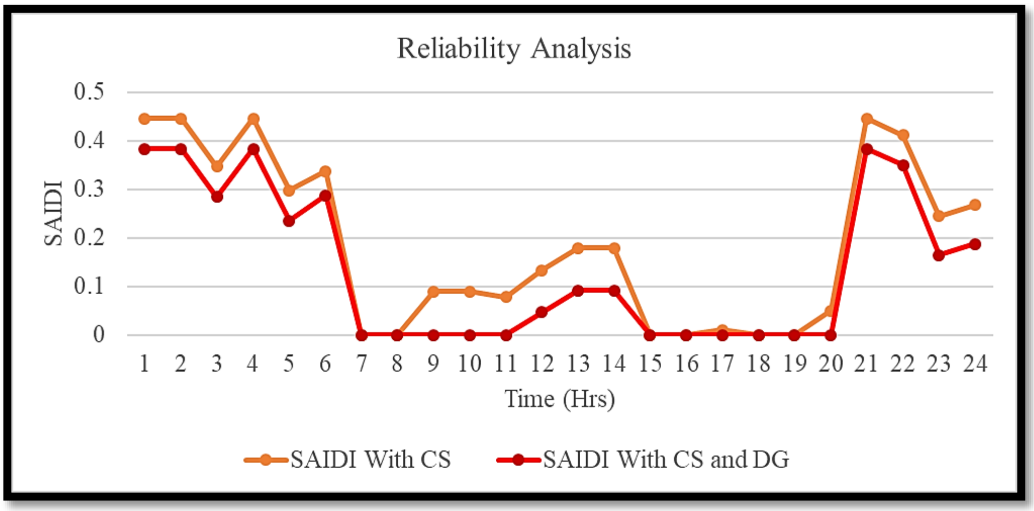

Figure 10 Reliability Analysis

The Figure 10 shows the reliability analysis before and after integration of DG. The SAIDI value is calculated for 24 hours. The SAIDI value is calculated for 24 hours. The SAIDI value before integration of Distribution Generation is 4.4908 and after integration of Distribution Generation is 2.9361. The number of customers interrupted 0n 1st hour is 98000. The SAIDI value is calculated for 24 hours. After integration of DG, the SAIDI value is decreased i.e. number of customers interrupted is decreased. The reliability is good after integration of DG.

Cost analysis

The size of DG is 396 kW which is calculated by PSO technique. In cost analysis we take different renewable energy resources that cost would be identified for per kW in dollars. That cost will be used to evaluate our distribution system requirement cost. They are two cost we can evaluate; they are capital and fixed operational and maintenance cost.

Capital cost analysis

- ✓ The capital cost of solar PV cell is 4410 $ per kW. So, the capital cost for DG of size 396 kW is 1746360 $.
- ✓ The capital cost of wind energy is 5127 $ per kW. So, the capital cost for DG of size 396 kW is 2030292 $.
- ✓ The capital cost of Biomass is 827 $ per kW. So, the capital cost for DG of size 396 kW is 327492 $.
- ✓ The capital cost of Ground source heat pump is 8554 $ per kW. So, the capital cost for DG of size 396 kW is 3387384 $.

Operational and maintenance cost analysis

- ✓ The operational and maintenance cost of solar PV cell is 20-40 $ per kW. So, the operational and maintenance cost for DG of size 396 kW is 7920-15840 $.
- ✓ The operational and maintenance cost of wind energy is 30-40 $ per kW. So, the operational and maintenance cost for DG of size 396 kW is 11880-15840 $.
- ✓ The operational and maintenance cost of Biomass is 100-130 $ per kW. So, the operational and maintenance cost for DG of size 396 kW is 39600-51480 $.
- ✓ The operational and maintenance cost of Ground source heat pump is 100-130 $ per kW. So, the operational and maintenance cost for DG of size 396 kW is 39600-51480 $.

VI. CONCLUSION:

12 bus radial distribution system is selected for analysing and the results are analysed. The charging station is integrated in distribution system for charging electric vehicle. The loss is increased after integrating charging station in the system. The Distribution generation is integrated in the system to improve reliability and reduce losses in the system. The transmission loss is reduced by placing Distribution Generation far away from the generating station. The optimal location for placement of Distributed Generation and charging station is determined by Loss Sensitivity Factor to have minimum loss. Backward and Forward sweep algorithm is performed and the power losses and voltage at each is determined. With the power losses and voltage, the LSF and normalized voltage is calculated. The optimal size of Distributed Generation is determined by PSO technique with objective of loss minimization. The reliability of the system with only charging is compared with the network with both CS and DG. The losses before integration of CS, after integration of charging station and after integration both CS and DG is compared. The cost is analysed for various generation of renewable energy. The losses in the system is reduced by integration of Distributed Generation and reliability is improved.

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