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Optimal Location of Small Hydro Power Plants ($SHPP_S$) at Distribution System by Using Voltage Sensitivity Index

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Abstract: This work presents a method to enhance the distribution network for both test and real systems by adding small hydro power plants (SHPPS). The voltage sensitivity index (VSI) was used to find the optimal locations to add small hydro power plants (SHPPS). The study has been applied to the system at unity and 0.9 lagging power factor. The test system is a standard IEEE 33-nodes radial distribution network. Maltab program was used to simulate the systems. The simulation results when connecting the (SHPPS) to the test system showed the improvement in voltage profile of the test system nodes in addition to power losses reduction. The reductions of the real and reactive power losses percentage reached (36%) and (14%) at unity power factor respectively, while at (0.9) lagging power factor, the reduction of the real and reactive power losses percentage were found (53%) and (56%) respectively.

Keywords: Distribution System, Loss Minimization, Voltage Profile, IEEE Bus System, Renewable Energy Sources (RESs), Small Hydropower Plant (SHP)

1. Introduction

The major considerations for any utility are to run at minimum cost, make maximum profit and to meet the customer demands all the time [1]. Nowadays, electrical utilities are undergoing rapid restructuring process and are planning to expand their electrical networks to meet the increasing load demand [2], but in fact traditional power plant expansion is a process that typically requires years for design, approval, installation and start-up. In a deregulated market environment, such processes are not the best alternative to follow deviations in the projected demand increase. Renewable energy resources have been considered as the best alternative to traditional fossil fuels [3]. The sizes of renewable energy based electricity generators would be very small as compared to large fossil fuel based power plant. Technically they are suitable for installation at low voltage distribution system, near loads centres [4]. Small hydropower system allows achieving self-sufficiency by using the best possible scarce natural resource that is the water, as a decentralized and low cost of energy production [5].

In the distribution systems, power losses reduction is one of the significant factors to improve the overall efficiency of the power delivery [6]. The term “distribution line losses” refers to the difference between the amount of energy delivered to the distribution system and the amount of energy customers billed. It is important to know the magnitude and causality factors for line losses because the cost of energy lost has recovered from customers [7]. Author in reference [8] represents techniques to minimize power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point of DG. Sensitivity analysis for power losses in terms of DG size and DG operating point has been performed. The method in reference [9] has based on the branch current and power flow. The final algorithm arrives at opening of a branch in a loop carrying minimum resistive power flow to make the network radial causing minimum loss.

In reference [10] the researchers used a non-dominated sorting genetic algorithm (NSGA) for reconfiguring a Radial Distribution Corporation to minimize its operating costs considering real and reactive power costs while maximizing its operating reliability and satisfying the regular operating constraints. Reference [11] proposed a new method that presents an algorithm for reconfiguration associated with capacitor allocation to minimize energy losses on radial electrical networks considering different load levels. The proposed model has been solved using a mixed integer non-linear programming approach, in which a continuous function has been used to handle the discrete variables. In reference [12] the researchers used real wind, solar, load, and cost data and a model of a reconfigurable distribution grid to show that reconfiguration allows a grid operator to reduce operational losses as well as to accept more intermittent renewable generation than a static configuration can. In order to minimize the total active power losses and improve the voltage profile of the power system, several solutions have been proposed including the integration of Distributed Generation (DG) in the radial distribution network. The way that used in [13] proposed an Algorithm for Firefly (FA) which is a met heuristic algorithm inspired by the behaviour of fireflies flashing. The main objective of Firefly flash is to act as signalling system to attract other fireflies. In reference [1], another method has been used by the Power System Analysis toolbox in MATLAB to minimize the cost of electricity with optimal power flow for the southern grid of Kerala State Electricity Board. This work concentrates on the savings with the incorporation of a wind farm in the system.

The research in [2] works at minimizing the real power loss in radial distribution system by Optimal Allocation and Sizing of Distributed Generation using Artificial Bee Colony Optimization (ABC) technique. The Artificial Bee Colony algorithm is a population-based optimization technique that based on the intelligent foraging behaviour of the honeybee swarm. To reduce the losses in distribution system, bionic random search plant growth simulation algorithm (PGSA) has been proposed using optimal capacitor placement in [14]. The reference [15] presents a simple method for real power loss reduction, voltage profile improvement, by using Heuristic Search and PSO optimization methods and Imperialist Competitive Algorithm (ICA). Optimally determine distributed generation location and size are compared in a distribution network, the research also demonstrates that system losses may increase if DG units are connected at non-optimal locations or have non-optimal size.

The authors explain in [16] a comparison of novel, combined loss sensitivity index vector and voltage sensitivity index methods for optimal location and sizing of distributed generation(DG) in a distribution network, the power injections from renewable DG units located close to the load centres provide an opportunity for system voltage support, reduction in energy losses and reliability improvement. Reference [6] proposes a new long term scheduling for optimal allocation and sizing of different types of Distributed Generation (DG) units in the distribution networks in order to minimize power losses. The optimization process is implemented by continuously changing the load of the system in the planning time horizon. In order to make the analysis more practical, the loads changed linearly in small steps of 1% from 50% to 150% of the actual value.

This paper focuses to minimize operating losses considering real and reactive power losses and to improve the voltages profile of a radial distribution system; the results will be displayed on the IEEE 33-node radial distribution network, which proposed to be the test system. The results before and after the addition of small hydro plants (SHPPS) were compared using the voltage sensitivity index (VSI).

2. Optimal Location Based on Voltage Sensitivity Index (VSI)

The main objective of finding VSI is to find most sensitive node of the system from voltage sensitivity point of view [17]. It considered a numerical solution, which helps operator to monitor how close the system is to collapse, or to initiate automatic remedial action schemes to prevent voltage collapse. Nodes, having minimum voltage sensitivity index are selected and then, using equation (1) to calculate the voltage sensitivity index (VSI).

When connecting (SHPPS) at bus i, VSI is defined as [18]:

$$\text{VSIi} = \sqrt{\frac{\sum_{k=1}^{n}(1-V_k)^2}{n}} \tag{1}$$

Where Vk is voltage at kth node and n is the number of nodes. The node with least VSI will be picked as the best location for the small hydro power plants (SHPPS) placement.

3. Results and Discussion

Results obtained for IEEE-33 test systems with VSI based method. The base MVA and base kV has been taken as: (MVA) Base=100MVA and (K.V) Base=33Kv.

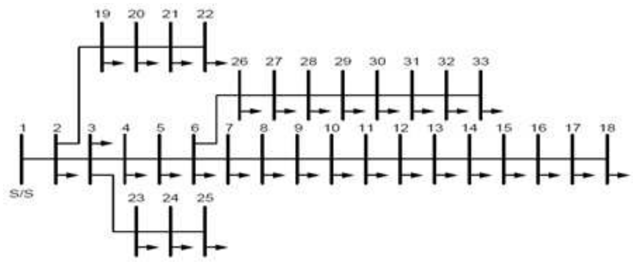

Figure (1). *Single Line Diagram of 33-Node Distribution System. [19]*

Table (1). *33-bus system with and without installation of small hydro power plants (SHPPS).*

	Without SHPPs	At Unity pf	At lagging pf
Real power from the substation MW	6.69034	4.84	4.705
Total real power loss MW	0.74634	0.350	0.241
Reactive power from the substation MVAR	3.96168	3.96168	2.911
Total reactive power loss MVAR	0.28168	0.242	0.09
Minimum bus voltage p.u	0.9184	0.9487	0.951
The source voltage p.u	1.001	1.003	1.004
Percentage of real losses %	11.15	7.2	5.14
Percentage of reactive losses %	7.11	6.11	3.09

Single Line Diagram of 33-Node Distribution System is shown in Figure (1) [19]. The results obtained at unity and 0.9 p.f (lag) for 33-bus system with and without installation of small hydro power plants (SHPPS) are shown in Table (1). The voltage profile for 33-bus system is shown in Figure (2). The size of (SHP) unit has been taken 2MW.

It is observed that, the losses are found lower with insulation of the small hydropower plants (SHPPS) at lagging power factor rather than (SHPPS) at unity power factor. This is due the reason of reactive power available locally for the loads and thereby decrease in the reactive power available from substation. The (VSI) profile for 33-bus system is shown in Figure (3).

The profile improves with (SHPPS) at unity and lagging power factor as shown in Figures (4) and (5) respectively. Thus, it is essential to consider the reactive power available from (SHPPS) and its impact on losses reduction and voltage profile improvement.

Figure (2). *Voltage profile for 33-bus system.*

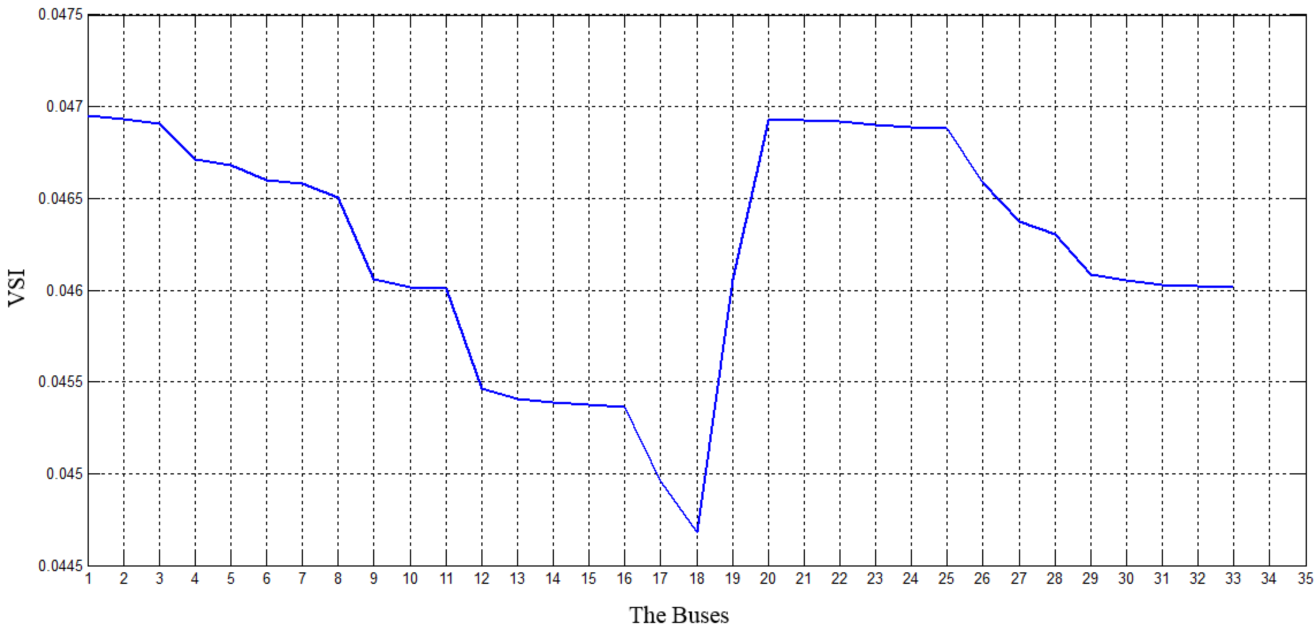

Figure (3). *VSI profile for 33-bus system.*

Figure (4). *Voltage profile for 33-bus system unity p.f.*

Figure (5). *Voltage profile for 33-bus system at 0.9 p.f lag.*

4. Conclusions

From the results obtained for real and reactive power losses, voltage profile; we can conclude that there is much reduction in real, reactive power losses and improvement in the voltage profile at 0.9 pf lag due to its reactive power supply to the system. Therefore, the proposed study at lagging power factor and supplying reactive power to the system is giving better results than unity power factor. From the results, it can be concluded that by introducing (SHPPS) in the system, voltage profile can be improved because (SHPPS) provide a portion of the real and reactive power to the load locally. The proper reactive power management and voltage profile with (SHPPS) will help toward the cost reduction due to the lower kVA requirements from the substation.

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