Research Article

Implementation of Distributed Generation with Solar Plants in a 132kV Grid Station at Layyah Using ETAP

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Received 11 January 2020; Revised 16 May 2020; Accepted 6 June 2020; Published 25 June 2020

Academic Editor: Raúl Gregor

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Decentralized power generation efficaciously merges technological advances in a rapidly changing face of power networks introducing new power system components, advanced control, renewable sources, elegant communication, and web technology paving the way for the so called smart grids. Distributed generation technology lies at the intersection point of power systems, power electronics, control engineering, renewable energy, and communication systems which are not mutually exclusive subjects. Key features of renewable integration in a distribution network include loss minimization, voltage stability, power quality improvement, and low-cost consumption resulting from abundant natural resources such as solar or wind energy. In this research work, a case study has been carried out at a 132 kV grid station of Layyah, Pakistan, which has active losses, reactive losses, low power factor, low voltage on the demand side, and overloaded transformers and distribution lines. As a result, power outage issue is frequent on the consumer side. To overcome this issue, a simulation of load flow of this system is performed using the Newton-Raphson method due to its less computational time, fewer iterations, fast convergence, and independence from slack bus selection. It finds the harsh condition in which there were 23 overloaded transformers, 38 overloaded distribution lines, poor voltage profile, and low power factor at the demand side. There is a deficit of 24 MW in the whole system along with 4.58 MW active and 12.30 MVAR reactive power losses. To remove power deficiency, distributed generation using solar plants is introduced to an 11 kV distribution system with a total of 24 units with each unit having a capacity of 1 MW. Consequently, active and reactive power losses are reduced to 0.548 MW and 0.834 MVAR, respectively. Furthermore, the voltage profile improves, the power factor enhances, and the line losses reduce to a great extent. Finally, overloaded transformers and distribution lines also return to normal working conditions.

1. Introduction

The global emerging trend of deregulated electricity market has underpinned a remarkable stride in the paradigm of distributed or dispersed generation (DG) by the use of small photovoltaic or wind plants to cope with the inevitable shortcomings such as power outage, poor quality, voltage regulation, and increased component losses in commercial and domestic infrastructure [1, 2]. These small power plants installed at subsequent stations not only pro-

vide better services to the consumers as backup sources but also eliminate pollution, greenhouse gas emission, and global warming [3]. DG ranging from a few kW to MW is now part of distributed energy resources which includes responsive loads and energy storage [4]. It also reduces the need for the distribution and transmission expansion with the essential requirements of huge power plants [5]. The most attractive prospect lies in the fact that DG is installed around the network that is close to the consumer's side to minimize power losses and voltage drops [6].

The implementation of DG by renewable energy resources is advantageous in rural areas specifically to stabilize the power grid and ensure reliability at reduced cost of generation and distribution [7, 8]. In order to exploit the full potential of DG, versatile and competent work force is required to cope with the broad spectrum of technical challenges. Few of the associated issues hindering the robust operation are the requirements of decentralized control [9], optimal placement of plants [3, 10], fault location [11], distribution system protection [12], reconfiguration [13], and integration [14].

The last decade has been dedicated to the implementation of the DG framework to furnish its overwhelming features to the power system community such as voltage stability and loss minimization [15]. Injeti and Kumar analytically determined the placement and sizing of DG for planning and operation of active distribution networks using fuzzy logic [16]. They carried out a detailed performance analysis on 12-bus, 33-bus, and 69-bus radial distribution networks to conclude an enhanced voltage stability factor at minimum losses. Mehta et al. proposed a selection scheme of the best type of DG unit and its optimal location by analyzing the voltage sensitivity index and bus participation factors using a power flow algorithm and modal analysis technique [17]. With these protocols, they were able to enhance the voltage stability of the distribution network with simultaneous improvement in the voltage profile for the 33- and 136-node radial distribution network. Onlam et al. proposed a novel optimization technique called the adaptive shuffled frog-leaping algorithm to solve the network reconfiguration and DG placement problems in IEEE 33- and 69-bus distribution systems [18]. They defined specific objective functions taking into account power loss minimization and voltage stability index improvement (VSI) and concluded that the power loss and VSI provided by this algorithm were better than all other protocols in both 33- and 69-bus systems. Rudresha et al. presented a method to determine the proper size and location of DG in a distribution system to reduce the losses and improve the voltage stability for different loading conditions [19]. They considered the IEEE 33-bus system to simulate the voltage profile and losses in the system and concluded that proper placement and sizing of DG potentially reduce the losses, improve the voltage profile, and thereby improve the voltage stability.

This paper deals with a comprehensive investigation of a 132 kV grid station in Layyah, a backward city surrounded by deserts in the southern part of Punjab Province in Pakistan. Due to the growing population, inevitable electricity needs, and negligence from the country's policy makers, the power infrastructure in Layyah is facing adverse stress to provide reliable, continuous, and quality services to the consumers. On the brighter side, the considered district holds the most favourable climatic conditions because sun shines for longer duration and there are extremely low chances of cloudy or rainy weather throughout the year implying maximum potential for solar energy. In the first part of the research, the whole grid station of Layyah including three zones consisting of 24 distribution transformers each is simulated on

an Electrical Transient Analysis Program (ETAP) power flow solver using the Newton-Raphson algorithm. The Newton-Raphson method provides a fast load flow solution without computing the superior order of derivatives for solving the small-, medium-, and large-scale distribution system and gives efficient results for computational cost minimization [20, 21]. Moreover, the results from the Newton-Raphson method are more reliable with a higher success rate of convergence as compared to those from the other power flow algorithms [22]. In this regard, the ETAP software is excellent for system planning and it has a positive effect on the test feeder so it can be employed for optimum size and location of DG in the substation [23]. Simulation results performed on this platform reliably predict the superiority and effectiveness of the proposed methods [24]. The network layout, component ratings, and all operating values considered in the simulation are based on the actual data of the region [25].

As a result of the computation, certain overloaded transformers and distribution lines of the existing network are identified causing load shedding, voltage deterioration, enhanced losses, and low power factor. In the second part of the research, the simulated power network of Layyah is upgraded to a DG network by the installation of distributed solar power plants of 1 MW each at subsequent intervals along the 11 kV bus in all the zones of the grid station. Moreover, the underrated transformers and distribution lines are replaced with new higher rated components to circumvent overloading and failure issues. As suggested by the results, all components of the network operate under normal loading conditions, and the voltage profile and power factor at each load side improved substantially with a considerable reduction in the losses across each transformer and distribution line.

Figure 1 shows a single-line diagram of a 132 kV grid station of Layyah in which three isolators (81-1, 82-1, and 83-1) at three legs leading to zones A-C are connected to the main 132 kV bus. There is one current transformer specified by symbol "E" which has two available current transformation ratios of 100/5 A and 200/5 A. Subsequently, each leg has an SF-6-type circuit breaker and lightening arrester (LA) followed by a primary distribution transformer (132/11.5 kV) of 20/26 MVA rating. There is one more current transformer with transformation ratios of 1600/5 A and 800/5 A followed by a potential transformer (11500/35 V).

The grid of 132 kV shown in Figure 1 splits into three primary distribution networks which are categorized into three zones: zone A, zone B, and zone C. The schematic diagram of the individual zone of the distribution network is shown in Figure 2. Each zone consists of further two 11.5 kV branches with each branch having 12 transformers connected to it for secondary distribution to the consumers. In this way, each zone is fulfilling demand to 24 regions of consumers. The simulation results of the existing system indicate that there are 23 transformers and 38 distribution lines in total which are overloaded and are represented by red colors. The voltage profile is found out to be around 300 V which is much smaller than the

FIGURE 1: 132 kV grid station installed at Layyah, Pakistan [26].

FIGURE 2: DG in different zones with overloaded transformers and distribution lines.

nominal value of 380 V. The power factor across all the zones is fluctuating around 0.7, and there are considerable losses across the transformers and distribution lines. In the new designed system, firstly, these transformers and distribution lines are replaced by highly rated components. In the second step, eight solar plants (Suntech, monocrystalline) of 1 MW power each are connected to the grid such that each branch is assisted with four units as shown in Figure 2. Each solar plant consists of 80 cells in series and 80 cells in parallel with each cell having the rating of 180 W. After solving the new system, it is established that the voltage level returns to around 380 V with a power factor of unity in the system. All losses in the system also reduce considerably.

This paper is organized as follows. Section 2 deals with current and future trends of electricity needs, power generation, annual demand factor, and power losses in the whole country. Section 3 discusses the Newton-Raphson power flow algorithm. In Section 4, the implementations of the existing system and new system are described in detail along with the discussion of results. Finally, conclusions are drawn in Section 5.

2. Current and Future Trends in Pakistan

In Pakistan, National Transmission & Despatch Company (NTDC) has designed a future load forecasting from 2017 to 2040 in which installed capacity and peak demands are highlighted at the end of each year. Although installed capacity was more than the total demand of electricity even in the past, the shortage of electricity is due to high losses and plants not running at full capacity. In 2017, the installed capacity was 137328 GWh, but the demand was 25717 MW. Future generation capacity and peak demand are shown in Figure 3. In 2040, the total installed capacity will reach 630529 GWh and the peak demand will reach up to 110736 MW [27]. Pakistan cannot fulfil its peak demand because most of the generating power plants are not running at rated capacity causing shortage of power in each state. The Quaid-e-Azam solar power plant has been installed in Bahawalpur, Pakistan, which has 1000 MW generation capacity but 400 MW is in operation and 600 MW is under progress. Some more projects including hydro and renewable energy sources like solar, wind, biomass, and geothermal energy sources are under discussion for the expansion.

The demand factor of load varies from month to month depending on the daily activities of the population and the season. In the month of February, it has a minimum value of 0.58. The maximum demand is unity in the month of June since it is the hottest working month of the year before summer vacations in institutes [27]. A month-wise graph of the demand factor is shown in Figure 4.

In Pakistan, transmission and distribution losses vary from year to year which are plotted in Figure 5 from the actual data taken from NTDC [28]. The transmission and distribution in Pakistan are not yet reliable which can be observed from the data taken from the fiscal years 1981 to 2018. In 1981, losses were 29.5% which were reduced to some extent after every year [28]. In 2017, the lowest losses of 19.4% were recorded in the system which again surged to 20% in 2018.

At the proposed site, power generation is less and power consumption is more due to which the system has increased losses, load fluctuations, and higher possibility of instrument interruption. A case study has been taken for solving the problem of load shedding, active and reactive losses, and low power factor and for improving the voltage profile. The data has been taken from the 132 kV grid station at Layyah, Pakistan. There is a problem of load shedding and a low power factor which has a minimum value of 0.69 and an average value of 0.84 in all the three zones. Minimum far end consumers' voltage is 283 V which is very less than the

FIGURE 3: Future load forecasting of the peak demand and installed capacity.

FIGURE 4: Year-wise demand factor of load in Pakistan.

transmitted value of 380 V. There was also a deficit of 24 MW power compared to the total demand at the grid. There are three zones in the 132 kV grid where each zone has an almost 8 MW energy deficit. So consumer energy demand cannot be fulfilled, and daily 6- to 8-hour load shedding is a routine.

To solve this problem, two techniques are valuable: the first one is to inject a DG to the load side and the second is that the grid station should be upgraded to 220 kV which necessitates higher upgradation cost. Here, DG injection can solve this issue with minimal cost and flexibility in the choice of the installation venue. The ETAP software is used to simulate the existing system and the new system. The old system has more losses than the new system. Power deficit is also removed by injection of the solar system which has a total of 24 MW rated output in which each unit has 1 MW generation capacity.

FIGURE 5: Power losses at transmission and distribution from 1981 to 2018.

FIGURE 6: Simulation diagram of a 132 kV grid connected to three 20 MVA transformers.

3. Power Flow Analysis

Power flow studies are of paramount importance for power system planning and upgradation and for determining the best operation of existing systems. The power flow problem can be solved by considering the admittance matrices of the network incorporating all the buses and feeders using a single-line diagram. All the buses are categorized as either voltage-controlled bus (or PV bus), load bus (or PQ bus) and slack bus (mostly bus 1). The Newton-Raphson method being the most efficient method in all aspects is used for solving power flow problems which also eliminates the need to explicitly specify the slack bus. The Taylor series expansion up to two initial terms is the basis for solving a multivariable nonlinear equation in a polar form with equal number of unknowns. The Newton-Raphson method is used for analysis of the 132 kV grid station at Layyah because of its convergence which is very fast and independent of size of buses, and little number of iterations is required for the solution of load flow. The convergence process of the multivariable Newton-

FIGURE 7: Transformer ratings and route lengths in (a) zone A, (b) zone B, and (c) zone C.

TABLE 1: Specifications of the existing system.

Name of parameters	Assumptions for parameter
System type	Three-phase AC system
Type of distribution line	Overhead line conductors
Type of load	Constant load
Standard frequency	50 Hz
Standard voltage	380 V (L-L)
Type of conductors	Aluminium conductor steel reinforced (ASCR)
Voltage limits	Critical over voltage > 105%, critical under voltage < 95%, marginal over voltage > 102%, marginal under voltage < 97
Bus 1	Reference bus or slack bus

Raphson method is explained below.

$$\begin{aligned}
 S_i &= P_i + jQ_i = V_i \sum_{k=1}^n Y_{ik}^* V_k^* = \sum_{k=1}^n V_i V_k Y_{ik} e^{j(\delta_i - \delta_k - \delta_{ik})}, \\
 P_i &= \sum_{k=1}^n V_i V_k Y_{ik} \cos(\delta_i - \delta_k - \delta_{ik}), \\
 Q_i &= \sum_{k=1}^n V_i V_k Y_{ik} \sin(\delta_i - \delta_k - \delta_{ik}).
 \end{aligned}
 \tag{1}$$

P_i and Q_i are the active and reactive powers, respectively.

$$\begin{aligned}
 f &= \begin{bmatrix} P_i \\ Q_i \end{bmatrix}, \\
 x &= \begin{bmatrix} \delta_i \\ |V_i| \end{bmatrix}.
 \end{aligned}
 \tag{2}$$

When more variables are involved, f' is replaced by the partial derivatives of P_i and Q_i with respect to the two entries in column vector x . The resultant matrix f' shown in Equation (3) is also called the Jacobian matrix.

$$f' = \begin{bmatrix} \frac{\partial P_i}{\partial \delta_i} & \frac{\partial P_i}{\partial |V_i|} \\ \frac{\partial Q_i}{\partial \delta_i} & \frac{\partial Q_i}{\partial |V_i|} \end{bmatrix},
 \tag{3}$$

$$\begin{aligned}
 \begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix} &= \begin{bmatrix} P_{i(\text{sch})} \\ Q_{i(\text{sch})} \end{bmatrix} - \begin{bmatrix} P_{i(\text{cal})} \\ Q_{i(\text{cal})} \end{bmatrix} \\
 &= f' \begin{bmatrix} \Delta \delta_i \\ \Delta |V_i| \end{bmatrix},
 \end{aligned}
 \tag{4}$$

$$\begin{bmatrix} \Delta \delta_i \\ \Delta |V_i| \end{bmatrix} = [f']^{-1} \begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix}.
 \tag{5}$$

The subscript cal denotes the calculated value and sch represents the scheduled values. The iterative process stops

FIGURE 8: Implementation of zone A of the existing system on ETAP.

when the mismatches become smaller than the specified tolerance ϵ , i.e.,

$$\begin{bmatrix} \Delta P_i \\ \Delta Q_i \end{bmatrix} \leq \epsilon. \quad (6)$$

It should be noted that the entries in the calculation process exclude the slack bus so there will be $n - 1$ buses for which the computation will be carried out.

4. Results and Discussion

A case study of the 132 kV grid station at Layyah has been simulated on ETAP. The grid station is divided into three zones, namely, zone A, zone B, and zone C. At the distribution level, 72 distribution transformers are connected to the load. There are 24 transformers in each zone and a main power transformer connected to the grid having the rating of 20 MW. After simulating the system, it appears that a few transformers are overloaded which can be observed from their highlighted red color in the simulation in Figure 6. The three main transformers of zone A, zone B, and zone C are also overloaded. In addition, the loads are located at suffi-

ciently large distance from the transformers. As a result, the system has transmission line losses, low power factor, and poor voltage regulation due to overloading which are the main issues in the grid. In particular, during the peak hours, the power demand is higher than the generation, so the overall system is not healthy to fulfil power demands to the consumers. The ratings of all transformers along with their distance from the load side in the three zones are plotted in Figure 7.

4.1. Existing System Implementation on ETAP. In order to analyze the power flow of the three zones, implementation of the grid is done on the ETAP software. The specifications of the existing system are shown in Table 1, and the same are considered in the simulation settings.

A 132 kV grid is implemented on the ETAP software whose layout is shown in Figures 6 and 8–10. When the program runs on ETAP, the following results are obtained. The three main transformers of individual zones having ratings of 20 MVA each are overloaded as shown in Figure 6 by their red colors. Moreover, in zone A, 11 transformers are overloaded which are connected to the sugar mill colony, the employees' colony, Noorabad, Chandiawala, the Q.H. scheme, the lawyers' colony, Qadeerabad, Laskaniwala,

FIGURE 9: Implementation of zone B of the existing system on ETAP.

Sirgani Thal, Maujgarh, and Shahpur Thal. In zone A, 18 distribution lines are overloaded which are L1, L9, L10, L15, L16, L20, L21, L22, L23, L24, L36, L41, L43, L44, L45, L46, L47, and L48. For the sake of saving space, numbers are only mentioned for the first four and last two lines. The marginally and fully overloaded transformers are shown in pink and red colors, respectively, and the overloaded distribution lines are shown in red colors in Figure 8.

In zone B, eight transformers and twelve lines are overloaded. The overloaded transformers are connected to Lohachthal, Zard, Jhoralnashib, Jakharpacca, Kharal Azeem, Khokharwala, Rakh, and Shahwala. Lines which are overloaded include L59, L83, L84, L86, L88, L90, L91, L92, L93, L94, L95, and L96.

Finally, in zone C, four transformers are overloaded. These transformers are connected to Saeed Nasheeb, Lad-hana, Jamanshah, and Awanwala. There are eight lines which are overloaded. These distribution lines are L97, L109, L131,

L132, L133, L139, L140, and L142. As a result of overloading, there is an observed deficit of 24 MW resulting into 6 to 8 hours of load shedding every day.

4.2. New Design of the 132 kV Grid Station. At the distribution side, solar cell modules are installed at uniform intervals after each third distribution line to overcome the problems of power shortage, voltage regulation, and low power factor. There is a deficit of 8 MW in each zone, so eight solar panels of 1 MW rating each are installed in each zone. The solar panel is installed at the distribution end or close to the user end to balance deficit and reduce line losses. The single-line diagram of the grid and all the three zones of the new system are shown in Figures 11–14, respectively.

After the installation of distributed solar panels in each zone, considerable power is extracted from the DG sets which causes less burden on each zonal transformer (20 MVA). Hence, all three zonal transformers return to their normal

FIGURE 10: Implementation of zone C of the existing system on ETAP.

FIGURE 11: Simulation diagram of a 132 kV grid after DG injection.

operating regimes despite having the same power rating as before. In addition, the overloaded transformers and distribution lines are replaced with higher rating components due to which their overloading problems are also eliminated. These facts can be observed from Figures 12–14 for zone A,

zone B, and zone C, respectively. Finally, all the problems of low power factor, voltage regulation, and power losses in transformers and transmission lines occurring in the system are resolved. The comparison of results between the existing system and the new simulated system is done in the next section.

4.3. Zone A: Transformer, Distribution Lines, and Load Analysis. In zone A of the existing system, 11 transformers are overloaded. Due to the overloaded transformers, the system is unbalanced. To overcome this problem, new transformers of higher rating are connected to replace the old ones and avoid overheating of transformers. As a result, the system reliability is increased and transformer losses are also reduced. A comparison between old and new ratings is shown in Figure 15.

DG at the load side has reduced losses to a great extent. It has increased cost for replacing new transformers but fulfilled the demand of customers. Transformer losses reach up to 18 kW in the old case which remain below 6 kW for the DG-injected system. Losses across each transformer in the old system and the new system are plotted in Figure 16(a).

FIGURE 12: Implementation of zone A of the new system on ETAP.

Lines losses are also reduced when DG is injected to the load side by replacing lines with proper ratings. The existing 17 distribution lines having the capacity of 267 MW are overloaded, and they are replaced with new lines with a rating of 500 MW. Line losses reach up to 110 kW in the existing system which remain below 11 kW for the proposed system. A graph is shown in Figure 16(b) which compares line losses in the old and new systems.

The power factor of load is improved when DG is injected at the load side. So the new power factor is slightly less than unity which is a good sign for a robust power system. A high power factor also reduces the cost of equipment because equipment cost under a low power factor is high due to high current ratings. A high power factor reduces the copper losses because the phase component of the current is reduced. It has also decreased the losses and voltage regulation which were occurring due to the low power factor. The graph of power factors and voltage profiles at the load side for zone A is shown in Figures 17(a) and 17(b).

The power factor for specific loads is better (>0.9) in the existing system; however, it stays below 0.85 for most of the connected loads. In the simulated system, the power factor has improved drastically to around unity. Voltage, on the other hand, has sufficiently small values at the load side which vary mostly between 300 V and 320 V. The desired value of voltage is 380 V (3- Φ line-to-line voltage) which is successfully achieved by photovoltaic installation.

4.4. Zone B: Transformer, Distribution Lines, and Load Analysis. Zone B consists of 24 transformers, 24 loads, and 48 lines. In the existing system, 4 transformers are overloaded requiring new transformers of better ratings to be installed. A comparison between old and new ratings is shown in Figure 18.

After replacing old transformers with those of better ratings, losses are reduced considerably as in the previous case. Transformer losses which were reaching 38 kW are now reduced to smaller values with maximum approaching

FIGURE 13: Implementation of zone B of the new system on ETAP.

11 kW. Old transformer losses and new transformer losses for zone B are plotted in Figure 19(a).

Line losses are also reduced after the installation of DG and by replacing distribution lines of proper ratings. Seven distribution lines (267 A) are overloaded and are replaced with 500 A lines. Consequently, line losses reduce and stay below 12 kW which were approaching 120 kW in the existing system. A graph is shown in Figure 19(a) that compares old system line losses and new system line losses.

The power factor of load is improved when DG is injected at the load side. So the new power factor is close to unity as in the previous case. It also reduces the losses and improves voltage regulation. The power factor in the old sys-

tem fluctuates and reaches up to a minimum of 0.73 which is improved to around unity with DG injection. The voltage also stays below 350 V; however, it stays higher than 375 V for the new system. The graphs of the power factor and voltage profiles are shown in Figures 20(a) and 20(b), respectively.

4.5. Zone C: Transformer, Distribution Lines, and Load Analysis. Zone C consists of 24 transformers, 24 loads, and 48 lines. In the existing system, 8 transformers are overloaded. To overcome this problem, new transformers are connected to the load. A comparison between old and new ratings for zone C is shown in Figure 21.

FIGURE 14: Implementation of zone C of the new system on ETAP.

FIGURE 15: Actual and new rating of transformers in zone A.

When transformers of proper ratings are used, losses reduce to a great extent. In the old system, transformer losses were reaching 30 kW and they reach up to 6.5 kW for the new system. The graph of transformer losses is shown in Figure 22(a).

Line losses are reduced when DG is injected and by replacing lines of proper ratings. Twelve distribution lines are overloaded and are replaced with 500 MW lines in the system. In zone C too, line losses are approaching 120 kW which reduces to around 6 kW for the new system. A graph is shown in Figure 22(b) showing the line losses in the existing and updated systems. The power factor of the load is improved when DG is injected at the load side. Again for zone C, the new power factor is nearly unity. For the existing system, the power factor reduced to as low as 0.68 which improved after the DG injection. The graph between old and new power factors is shown in Figure 23(a).

The voltage profile is also improved as a result of DG injection. For the old system, the voltage level varied between

FIGURE 16: (a) Transformer losses and (b) line losses before and after DG in zone A.

FIGURE 17: (a) Power factor and (b) voltage at the receiving end in zone A.

FIGURE 18: Actual and new rating of transformers in zone B.

300 V and 340 V which improved substantially to around 378 V after photovoltaic injection. Old and new voltage levels are shown in Figure 23(b).

5. Conclusion

Pakistan is an underdeveloped country where energy crises are more and the overall economy is low. A case study has

been taken to observe load flow from the 132 kV grid station at Layyah. There are issues of power losses, poor voltage profile, low power factor, and overloaded transformers. To solve these issues, two techniques are available: one is to upgrade the grid to 220 kV and the other is to inject a DG system to fulfil the needs of the demand side. The second approach is adopted for the solution of problems. Three zones were designed on ETAP to simulate a power flow algorithm using the Newton-Raphson method and discussed one by one. Each zone consists of 24 transformers, 24 constant loads, and 48 cables.

Zone A has 24 transformers in which 11 transformers are overloaded and 18 distribution lines are overloaded. The load power factor is 0.71 at Shahpur Thal, and the lower voltage at Maujgarh was 293 V. When DG is injected in all transformers, distribution lines started working properly with minimum losses. Shahpur Thal's load power factor becomes 0.9975, and Maujgarh's voltage profile is improved from 293 V to 374 V. Similarly, losses reduced in every element, and also the power factor improvement is noticeable. Zone B has 24 transformers in which 8 transformers are overloaded, 12 distribution lines are overloaded, and the lowest power factor is 0.69 at Awanwala. The lowest voltage at Ladhana is 298 V. When DG is injected to all transformers, distribution lines started working in a proper way with minimum losses. Awanwala's power factor of loads became 0.9973. Ladhana's voltage profile improved from 298 V to

FIGURE 19: (a) Transformer losses and (b) line losses before and after DG in zone B.

FIGURE 20: (a) Power factor and (b) voltage at the receiving end in zone B.

FIGURE 21: Actual and new ratings of transformers in zone C.

374 V. Zone C has 24 transformers in which 4 transformers are overloaded, 8 distributions lines are overloaded, and the lowest power factor is 0.75 at Zard. The lowest voltage at Karlo is 283 V. When DG is injected, distribution lines started working properly with minimum losses. The power factor of loads in the Zard region becomes 0.9862. The voltage profile in the Karlo region improved from 283 V to

FIGURE 22: (a) Transformer losses and (b) line losses before and after DG in zone C.

FIGURE 23: (a) Power factor and (b) voltage at the receiving end in zone C.

375 V. Initially, total losses were 4.58 MW and 12.30 MVAR which were then reduced in the newly implemented system up to 0.548 MW and 0.834 MVAR. Load forecasting is done in this case study where more power is needed. In this design, old transformers were replaced by new transformers to save the consumer side from outages of power. Every zone needs 8 MW power, so 24 solar panels of 1 MW each were installed at the consumer side. This method has the potential to overcome the problem of load shedding as well, which is about 6 to 8 hours in the region.

Data Availability

The data used to support the findings of this study are included within the article. The data is cited at relevant places within the text as references.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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