

Design and planning of a distribution system using renewable technologies in a rural area of Pakistan

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Abstract: The inclusion of renewable energy sources in a distribution system to form a dispersed or decentralized generation network has gained tremendous progress in recent years. The architecture of the distribution system has the potential to serve as a microgrid during an islanding operation connected directly to the load center while excited fully by renewable technologies. This paper deals with planning and designing of a medium voltage power distribution system in a rural area of Pakistan affluent with abundant reserves of renewable sources of electricity. Two types of distribution system architectures, namely radial and ring systems, are simulated using a power flow algorithm with three types of renewable generation technologies: solar, wind, and biogas. The theoretical study involves realistic parameters such as total houses, estimated load, distance of the load from proposed generation site, solar irradiance, wind speed, and biogas reserves. As a result, transformer losses, line losses, power factor, and voltage profile across the load are evaluated for both system types and compared. It is concluded that the ring system maintains better voltage profile, higher power factor, and less transformer and line losses as compared to the radial system. All the relevant construction details together with the electrical and operational parameters of the power system need to be processed accurately in a computer program. Such a program has been modeled as part of this research with embedded methods and conditions outlined in this paper.

Key words: Distributed generation, radial system, ring system, line losses, power factor, power flow, islanding

1. Introduction

The face of electrical power systems is rapidly changing all over the world due to the growing needs of electrical energy to fulfill domestic and commercial objectives. With the growing trend, advanced methods and state-of-the-art equipment are being introduced to the power system community to reduce losses [1], minimize greenhouse gas emissions [2], ensure reliability [3], voltage stability [4, 5], improve power quality [6], and utilize renewable energy without adverse environmental effects [7, 8]. Due to the intermittent nature of renewable energy sources (RES), a control mechanism is required to smartly operate the bidirectional flow of power, storage systems, security and stability in both grid-tied and/or islanding mode [9]. Upgradation of existing medium voltage (MV) networks with RES is a global system approach where the potential candidates for these services are fuel cells, wind farms, PV plants, biogas generators, and thermal plants which are typically smaller in size [10]. The incorporation of these RES in potentially rich sites to form a microgrid eliminates voltage, thermal, and transformer instability issues [11].

The efficient implementation of dispersed generation (DG) in a MV distribution network for power sys-

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tem design, planning, and analysis calls for the inclusion of theoretical framework using efficient power flow algorithms embedded in a computer program. Apart from the conventional methods, more sophisticated solutions are proposed including backward sweep method [12], forward sweep method [13], node branch numbering scheme [14], direct solution [15], load admittance method [16], and linear data structure [17]. Despite the exotic nature of these unconventional power flow algorithms and their exquisite ability to forecast optimum power system layout, there remains a challenge of successful and fast convergence while modeling a spacious architecture with multiple renewable injections. For this reason, Newton Raphson power flow algorithm is concluded to be the robust program for modeling complex power networks in a broad spectrum of sophisticated appliances.

There exist four types of primitive architectures of distribution systems namely radial, ring, mesh, or aromatic with each of the type bearing unique features in terms of consistency and reliability of services to the consumers [18]. Radial network is the simplest, cheapest, and widely used type of distribution system; however, if a fault occurs at a certain point, all the lines in the downstream lose power due to its tree-like structure. Distribution systems are most often prone to natural disasters such as earth quakes, floods, and cyclones, and in the worst case, fault at a local node may cause power failure in all branches in the tree. Ring and mesh networks are relatively stable systems in terms of fault sensitivity since they maintain multiple connections towards a single load unit ensuring continuous supply even after connection failure. Although mesh and radial networks can be mutually transformed to one another by simply breaking or establishing proper connections among the buses respectively [19, 20], the path of power flow within the nodes modifies enormously causing major reforms in the end results.

Over the past decade, expedient and innovative exercises are being practiced for the performance enhancement and efficient fault detection in the distribution systems by adaptive algorithms. Surtijo performed energy loss calculation of a 20-kV distribution network and minimized effort using network reconfiguration [21]. He performed a simulation study over the region of PTPLN (Persero) UPJ Bantul and calculated energy losses per annum in the existing system to be 1.7%. After performing network reconfiguration by operating normally open and normally closed switches and changing the topology of the line, he reduced the system losses to 1%. Abdelmonem et al. demonstrated loss reduction in distribution networks by network reconfiguration taking into account bus voltage limits and thermal limits of network branches [1]. They formulated power flow equations in a modified form to incorporate opening/closing of tie switches and introduced embedded generators and shunt capacitors while preserving the radial configuration. After comparison with the published results, they concluded that the most appropriate topology of the system causes minimum distribution losses. Raut et al. demonstrated a Pareto multiobjective sine cosine algorithm for determining optimal location of DGs in a distribution system [22]. Due to the contradictory objectives, they determined an optimized Pareto set to help network operators make fast decisions. Wei et al. introduced a fundamental component shift and multiple-transient-feature fusion method to detect a single phase to ground fault in a distribution network [23]. They used the Hilbert transform and a shift factor to preserve all transient features and identified the feeder with maximum fault degree as the faulty feeder. Shaheen et al. proposed a backtracking search technique for feeder reconfiguration in (i) 11-kV Egyptian ring distribution network and (ii) 12.66-kV radial distribution system of 32 buses and 37 distribution segments [24]. Using power flow solutions, they concluded that the reconfiguration satisfactorily improved the voltage profile and minimized the losses and overloading in the branches. Malik et al. performed strategic planning of renewable DGs in a radial distribution network using multiobjective particle swarm optimization method and tested on Portuguese 94-bus system [25]. The simulation results revealed reduction in power loss up to 77.82%, in voltage deviation up to 9.68%, and in voltage stability index up to

44.25%. Recently, Behbahani et al. demonstrated reduction of voltage fluctuations by the reconfiguration of distribution network using discrete particle swarm optimization [26]. They considered IEEE 69- and 95-bus practical Iranian distribution network as a case study to analyze the fluctuating load (e.g., welder) which violates power quality standards. After performing network reconfiguration using normally open and closed switches, they developed optimization problem to mitigate the flicker, improve voltage profile, and reduce power losses.

Despite the voluminous research having been conducted to highlight network reconfiguration and its appealing outcomes, there has been quite a limited work available in the recent literature dealing with the analysis and comparison of electrical quantities between any two types of distribution networks. This paper deals with the implementation of DG in a rural area of Pakistan, Kadhan, a town in district Badin which is located in the southern part of the province of Sindh. The geographical location of this city maintains paramount importance due to the closeness to Karachi, the biggest industrial and coastal city of Pakistan. Furthermore, the studied district suffers lack of attention from provincial and local administration due to which there is no electricity for a community of around 6000 habitats. Surprisingly, the city is a rich recipient of solar irradiance, wind resource due to the closeness to sea, and biomass reserves since most people earn their living by cattle farming. A summary of available volume of biomass from cattle dung and the resultant power in the proposed district is provided in Table 1. Two types of well-known architectures namely radial and ring distribution systems are designed to distribute electricity for the local consumers. It is notable that no such work exists in the open literature dealing with design, analysis, and comparison of electrical performance of radial and ring distribution systems. The networks are designed such that there are four zones each having 20 load units and 20 transformers with specific ratings and lengths of distribution lines. In order to do analysis on comparable basis, the designing is done in such a way that the component ratings within the respective zones in the two architectures is exactly similar and the difference comes in the connections within the load and the generator buses. The design and planning of the network is carried out on the basis of number of existing houses and calculation of the total load of individual house after doing a survey. The network is fed by three types of available RES (solar, wind, and biomass) in an off-grid or islanding mode after evaluating the available potential making the city an autonomous power house. The schematic diagrams of the radial network and its converted ring counterpart are shown in Figures 1 and 2, respectively. As a result of power flow simulation, transformer losses, line losses, voltage profiles, and power factors across all components are evaluated. In addition to the reliability of services of the ring distribution system, it is found that the ring system provides promising features in terms of loss minimization and better power quality as compared to the radial analogue.

This paper is organized as follows: Section 2 deals with total load estimation of Kadhan Town in the Badin District and availability of RES ready for conversion to electricity. In Section 3, the implementation of MV distributed system excited with RES is demonstrated in Electrical Transient Analyzer Program (ETAP). Section 4 discusses the critical analysis and comparison of results for the two underlying systems in all four zones of the consumers. Finally, in Section 5, conclusions are drawn.

2. Demand and potential of green energy in Badin

The southern part of Sindh Province in Pakistan maintains paramount importance due to the closeness to sea and being the biggest industrial city of Karachi as evident from Figure 3. Other two major cities in close vicinity of Badin are Hyderabad and Nawabshah; however, both these cities are relatively far from the sea due to which they possess less favorable conditions for renewable sources, especially wind. The proximity of Badin to the sea causes its temperature to stay considerably low as compared to the central part of the country which

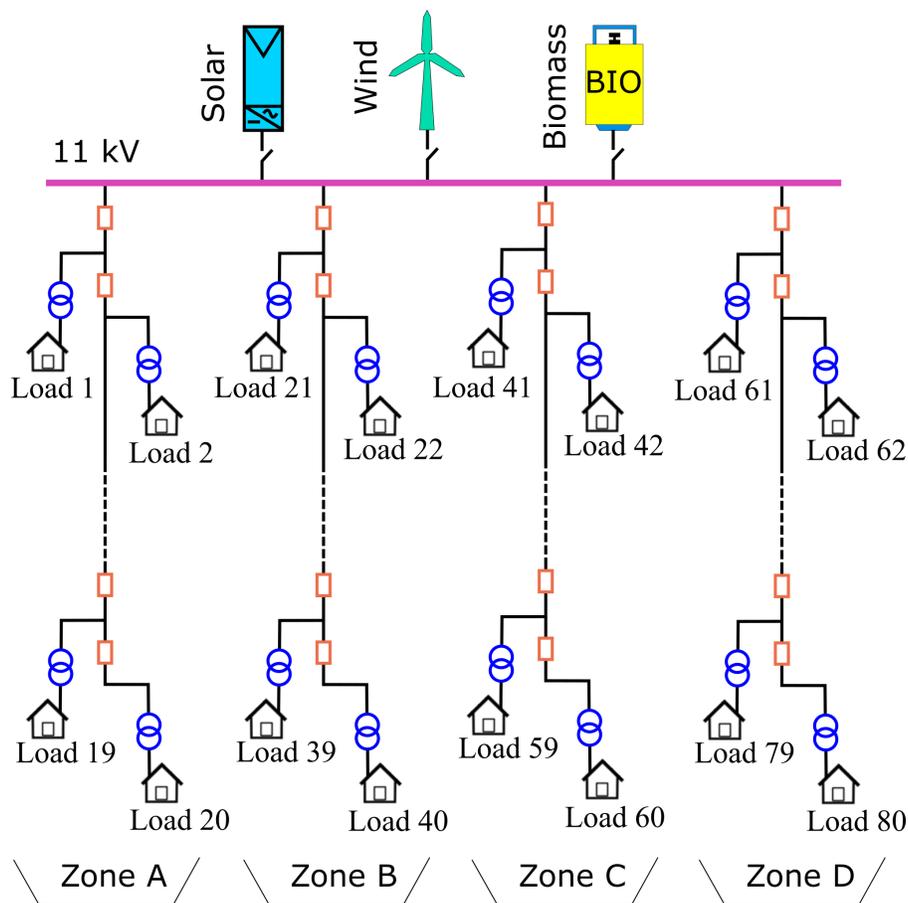


Figure 1. Schematic diagram of the radial distribution system in islanding mode with DG at MV bus.

is also a good prospect for solar PV operation. It should be noted that the electricity deficit exists in the whole country and power outage is a frequent issue even in large cities of Pakistan. Successful installation of a DG-based distribution system in Badin will not only empower its own community but also allow its surrounding developed cities to run at a steady pace. Furthermore, the capital cost of such an enormous project is inevitably on the higher side due to the congested land with higher price and rental tariffs in large industrial cities. This makes these adjacent rural areas with vast land at cheap prices more promising for power infrastructure development.

Figure 4 shows the weather data of Badin as recorded from World Weather Online website for the past 10 years in each month ¹. The irradiance/temperature data are plotted as a function of each month during a year on the left/right vertical axis, respectively. The irradiance in Badin ranges from 3.6 kW/m² in December to around 6.95 kW/m² in May. The temperature varies from 17 °C in January to 37.3 °C in June which is notably quite lower than that in the northern part of Sindh and the southern part of Punjab Province. The smaller temperature additionally enhances PV efficiency in the presence of abundant sunlight for longer duration.

Unlike solar power, the efficient operation of a wind turbine is the function of only one environmental

¹Badin Monthly Climate Averages (2020). World Weather [Online]
Website <https://www.worldweatheronline.com/lang/en-pk/badin-weather-averages/sindh/pk.aspx> [accessed 14 August 2020]

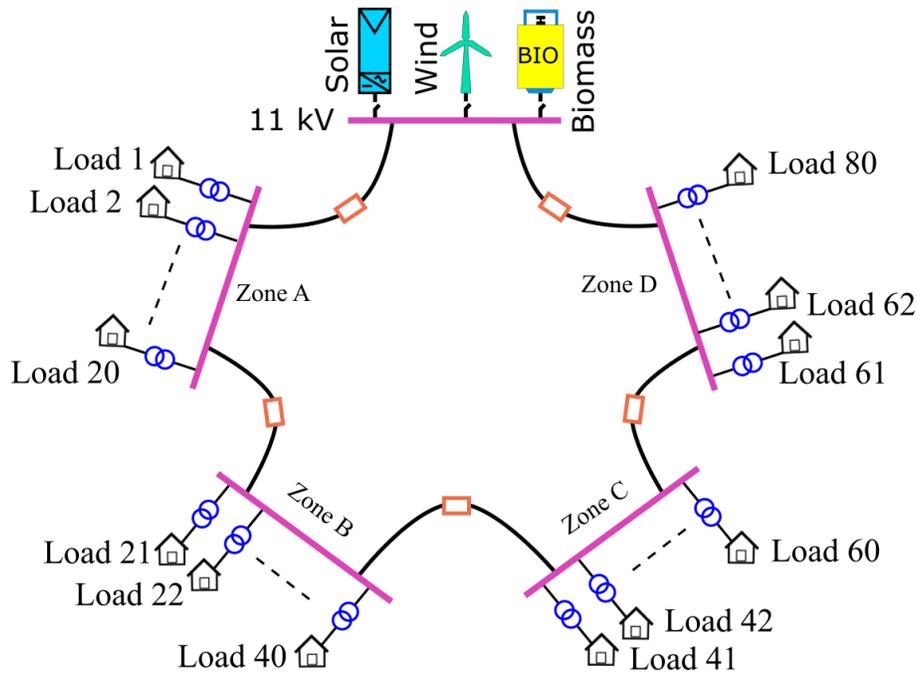


Figure 2. Schematic diagram of ring distribution system in islanding mode with DG at MV bus.

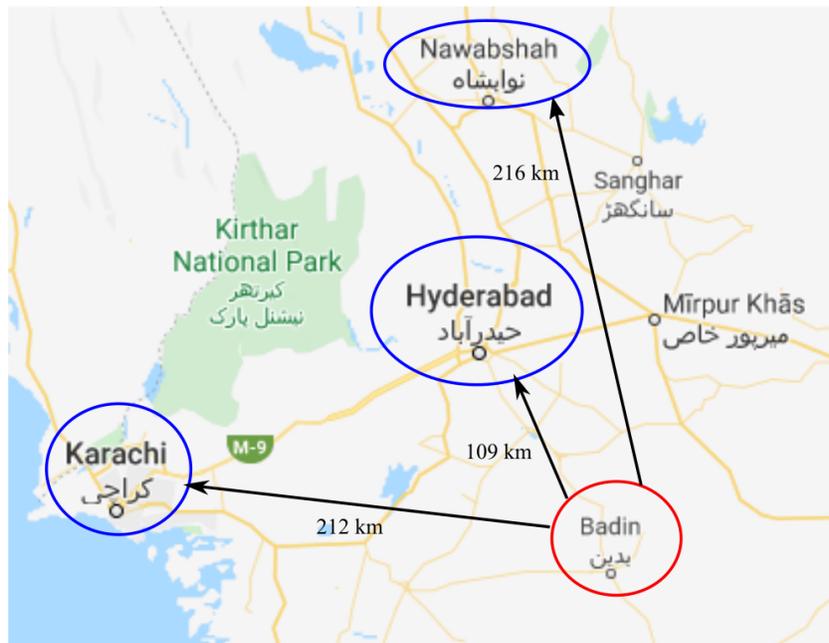


Figure 3. Geographical location of Badin.

parameter which is the wind speed irrespective of all other climatic conditions. The typical cut-in wind speed required to run a small turbine and produce electricity is 10.8 km/h [27]; however, a cut-in speed of as low as 2.34 m/s (8.42 km/h) with a specially designed turbine blade has been achieved [28]. Wind speed in the Badin

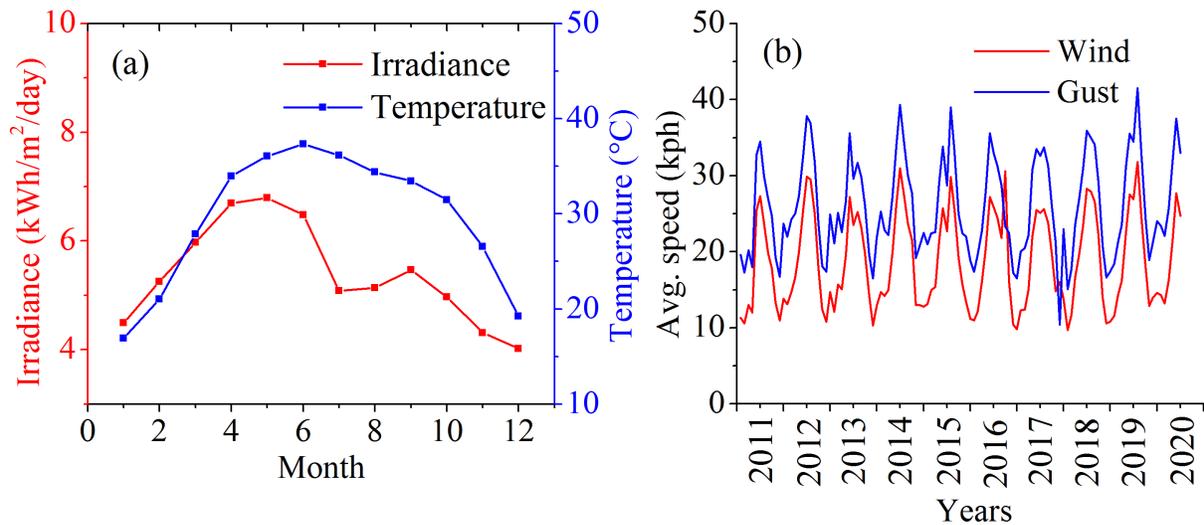


Figure 4. Weather data of (a) irradiance, temperature, and (b) wind in the Badin District.

District during the past 10 years is plotted in Figure 4b with normal wind and gust speed graphs together. A maximum of 41.5 km/h gust speed and 31.8 km/h wind speed are recorded in July 2019 whereas a minimum of 10.4 km/h gust and 9.7 km/h wind speeds are recorded in November 2017 and January 2018, respectively. Normally, wind speed is on the higher side during summer and on the lower side during winter which is in good agreement with the need of electricity by the consumers. These numbers show that, unlike solar power, the Badin region has a better potential for harvesting sufficient electrical power by wind throughout the day without the need of a storage system.

Table 1. Estimation of power generated from biomass available in Badin.

| | |
|--------------------------------------|---------------------|
| Average dung from one cow/buffalo | 20 kg |
| Total number of buffalos and cows | 1230 |
| Total dung obtained from cow/buffalo | 24600 kg |
| Total biogas produced | 1230 m ³ |
| Total power produced | 2.4 MW |

The last renewable technology implemented in this research work is biogas generation which is furnished by burning biofuel collected from animal manure. In rural areas of Pakistan, animal farming is one of the biggest sources of earning and animal waste is used for fertilizing the land and burning fire for cooking in areas with no supply of natural gas. According to one estimation, Pakistan has 33 million cows and 30 million buffaloes and each individual cattle produces 20 kg dung in one day. In the Badin District, cows and buffaloes are counted to be 1230 who are capable to produce 24,600 kg dung and consequently, 2.4 MW electricity in one day. The details of daily biogas and electricity production are summarized in Table 1².

The estimation of the total load in Kadhan Town, Badin was done by the survey of the region which was carried out by a team of three persons. The survey team visited a total of 30 houses in Kadhan Town

²BETAPAK (2010). Bio energy technology application Pakistan Website <http://betapk.org/potential.html> [accessed 16 August 2020]

Table 2. Load estimation of houses with 5, 8, and 10 persons in Badin.

| Load | Power | Quantity (5 people) | Quantity (8 people) | Quantity (10 people) |
|---------------|-------|---------------------|---------------------|----------------------|
| Lights | 13 W | 4 | 6 | 8 |
| Fans | 75 W | 3 | 5 | 7 |
| Refrigerators | 75 W | 1 | 1 | 1 |
| TV | 50 W | 1 | 2 | 3 |
| Misc. | 75 W | 1 | 2 | 3 |

from which 12 houses had a total of 5 people, 15 houses had a total of 8 people, and 3 houses had a total of 10 people living in each house. The load assignment is done in such a way that a house accommodating 5 people requires 4 lights, 3 fans, 1 refrigerator, 1 television (TV), and a total of 75 W as miscellaneous use of electricity [29]. A house accommodating 8 people requires 6 lights, 5 fans, 1 refrigerator, 2 TVs, and a total of 150 W as miscellaneous use of electricity. Finally, a house accommodating 10 people requires 8 lights, 7 fans, 1 refrigerator, 3 TVs, and a total of 225 W as miscellaneous use of electricity. In this way, the total load of 30 surveyed houses was calculated to be 20.6 kW. Considering a similar distribution for houses with different numbers of people for the remaining unexamined houses, the total load was calculated by multiplying the load of 30 houses with 200, which was calculated to be 4.13 MW.

3. Methodology

The electrification process of the whole Kadhan Town has been accomplished by doing power flow simulation using the three renewable technologies in ETAP software. This platform comprises fast and robust simulation of complex power networks excited by renewable sources using conventional power flow algorithms namely, (i) the Gauss–Siedel method, (ii) the Newton–Raphson method, and (iii) the fast decoupled method. Owing to the high success rate of convergence and requirement of less number of iterations, the Newton–Raphson method is assumed to be the most efficient for modeling complex power networks [30]. The model parameters and component types considered in the simulation are summarized in Table 3.

Table 3. Estimation of power generated from biomass available in Badin.

| | |
|-------------------|--|
| Parameter | Assumptions |
| Load type | Constant load |
| Conductor type | Aluminium conductor steel reinforced |
| Line model | Lumped parameter |
| Nominal voltage | 380 V |
| Distribution line | Overhead line conductors |
| System type | 3-phase AC |
| Nominal frequency | 50 Hz |
| Bus-1 | Slack bus |
| Voltage limits | Critical under voltage < 95%, critical over voltage > 105%, marginal under voltage < 97%, marginal over voltage < 102% |

Based on these parameters, two most commonly used distributed architectures namely (i) radial distribution and (ii) ring distribution systems are simulated. The details of individual components of the network and their arrangements are discussed in the next subsections.

3.1. Radial system implementation

Radial system of power distribution is the most common and simplest form of electrical network consisting of radially emanating distribution transformers from a single point of the bus. For small scale power networks, this architecture serves as a convenient platform for providing quality electricity to the consumers. However, for large-scale networks, consumers located near the far end may experience voltage regulation and unscheduled blackouts in case of fault occurrence. The whole region is divided into four zones namely, Zone A, Zone B, Zone C and Zone D with each comprising of 20 transformers namely T1 - T20 (11 kV/380 V) and 20 load units (Load1 - Load20). The simulation diagram of Zone A of the radial distribution system is shown in Figure 5 in which transformers are connected to load units through distribution lines of various lengths. The distance of load unit from the transformer and kVA of each load unit is calculated from the site survey and the kVA rating of each transformer is assumed to be equal to that of the corresponding load unit. In this way, the transformer overloading issues and voltage regulation due to transformer is eliminated and the overall system stays the most economical. The voltage values, transformer kVA, distribution line lengths, and active powers coming from the simulation are displayed along with each component. In Zone A, the active power flowing towards the load units ranges from 18 kW to 188 kW whereas the apparent power of the load ranges from 25 kVA to 200 kVA depending on the size of the load.

It is appraised that the structure of each zone in the radial network is exactly similar and the only difference comes in the electrical values across each component. To save space on the paper, the corresponding values of simulated apparent powers and distribution line lengths across each branch in Zones B, C, and D are plotted in Figures 6a-c, respectively. In Zone B, the distribution line length ranges from 2 km to 15 km and apparent power ranges from 21 kVA to 192 kVA. The distance of load from the transformer in Zone C ranges from 1.4 km to 18 km whereas apparent power ranges from 19 kVA to 193 kVA. Finally, in Zone D, the distribution line length ranges from 1.31 km to 16.1 km and apparent power varies between 22 kVA and 193 kVA. As expected, the active power in all zones is slightly smaller than the apparent power for most of the branches and equal to the apparent power at a few places as well, implying unity power factor.

3.2. Ring system implementation

The ring distribution system consists of five buses with bus-1 being the generator bus and four buses designated as load buses. Each transformer and its load unit is directly connected to its labeled bus and all five buses are connected together creating a ring. The simulation diagram of Zone A of the ring distribution system is shown in Figure 7 in which all load units and their corresponding transformers have identical ratings as in the case of Zone A of the radial system. The load bus is illustrated in purple color as 11 kV bus in Figure 5. The distribution line lengths and apparent powers for the ring system are exactly the same as those in the radial system in the previous subsection.

4. Results and discussion

The design of the simulation in the preceding section is followed by the investigation of the results which include transformer losses, line losses, voltage profiles, and power factors across all components. In this regard, all results

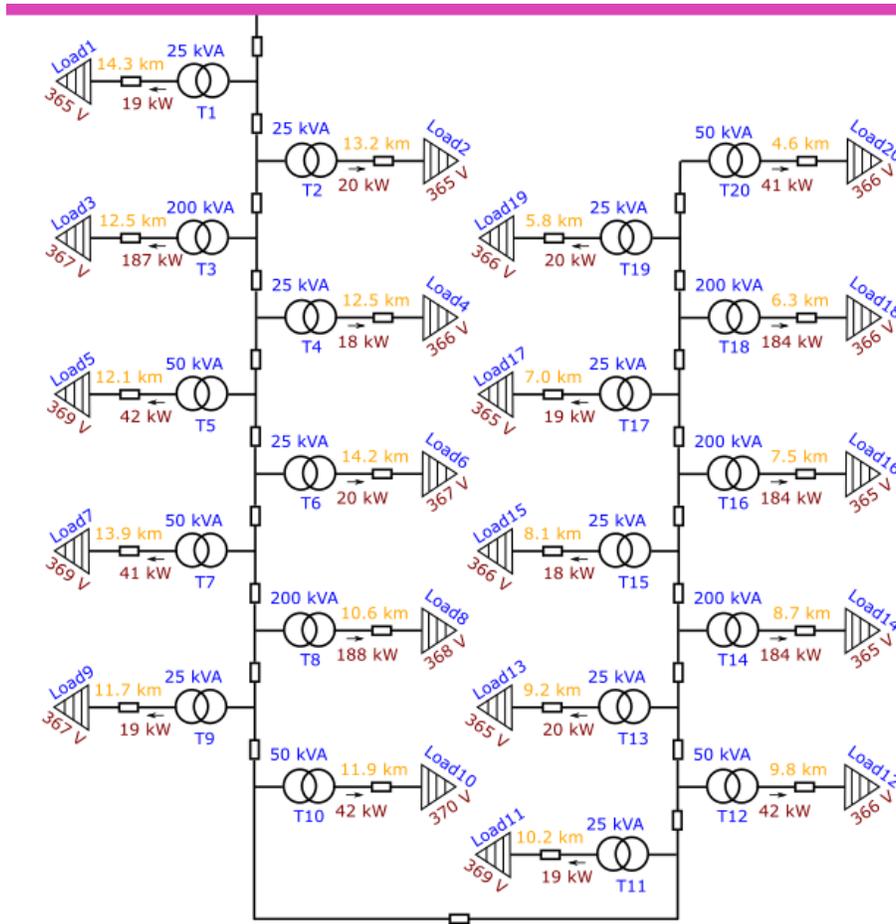


Figure 5. Zone A of the radial distribution system simulated in ETAP.

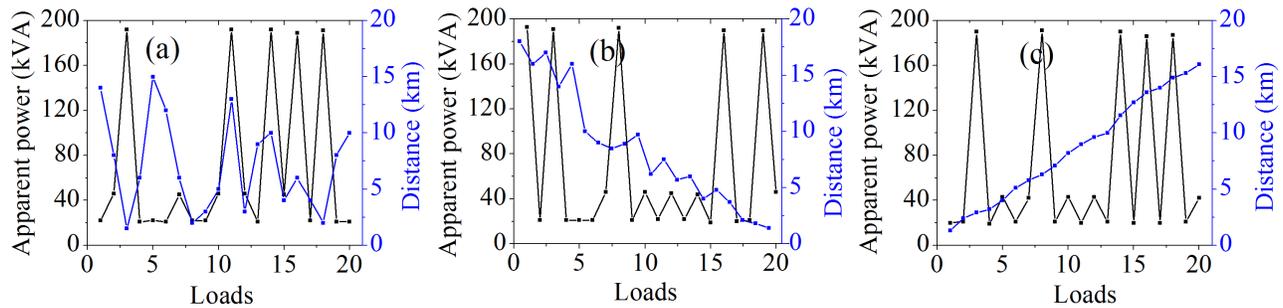


Figure 6. Active and apparent powers of (a) Zone B, (b) Zone C, and (c) Zone D of the radial distribution system.

for both the radial and ring distribution systems are plotted in the same figure to get a valid comparison. For each zone, the electrical parameters are plotted in separate subsections.

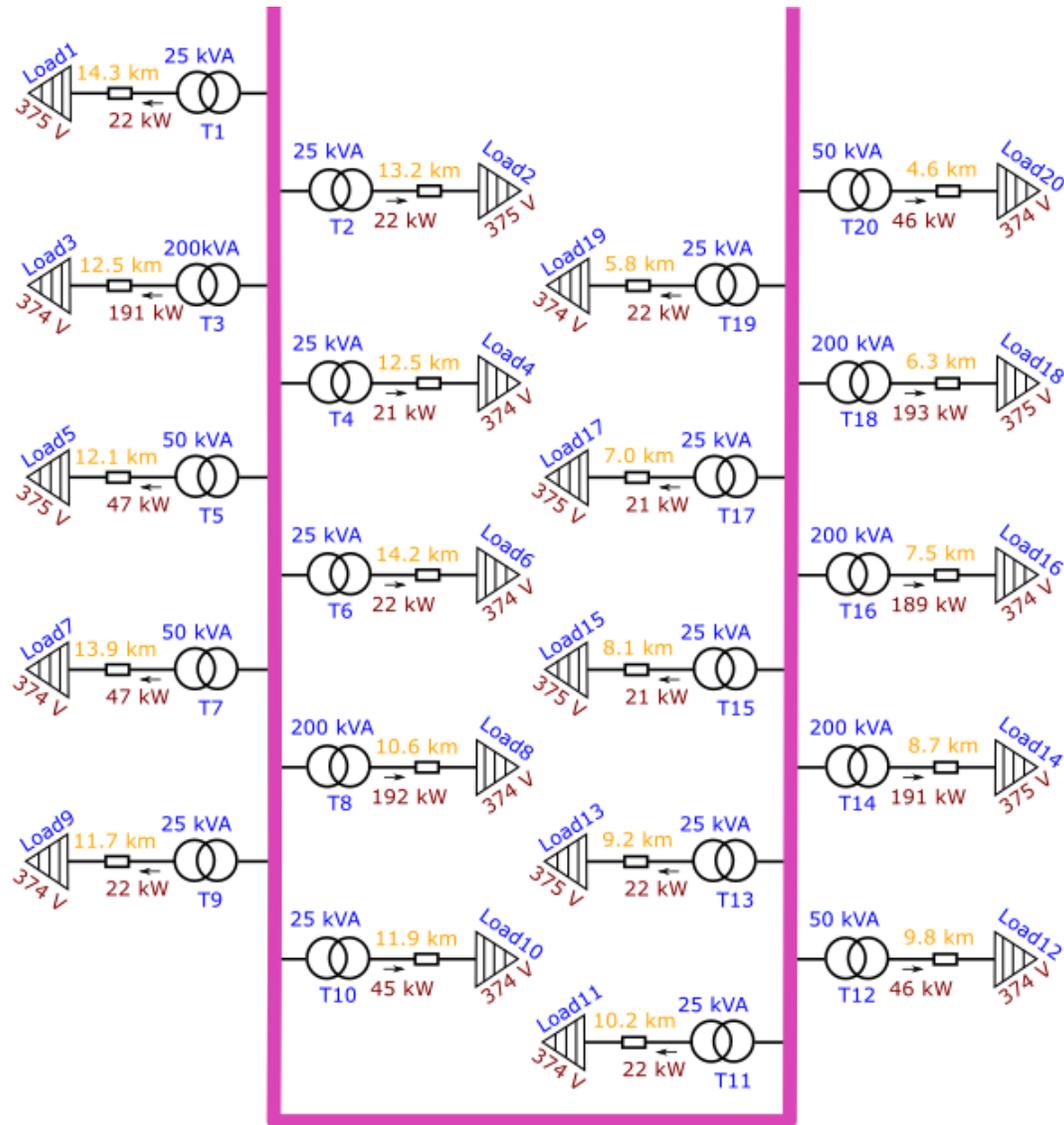


Figure 7. Zone A of ring distribution system simulated in ETAP.

4.1. Zone A

In Zone A, the transformer losses range from 2.5 kW for T11 to 5.9 kW for T7 for the radial system. In the ring system, the minimum transformer losses of 2 kW occur at T6 and T9 and the maximum loss of 4.6 kW occurs at T14. Line losses for the radial system are minimum up to 2.1 kW at line6 and maximum up to 5.4 kW occurring at line17. For the ring system, the minimum values of line losses are 0.4 kW at line2 and 3.1 kW at line15 and line16. The voltage varies from 365 V to 370 V for the radial system and from 374 V to 375 V in the ring system. Finally, power factor ranges from 0.85 to 0.89 for the radial system and from 0.87 to 0.92 in the ring system. Clearly, the radial system exhibits higher transformer/line losses, poor voltage profile, and relatively low load power factor as compared to the ring system. This is because the ring system involves feeding the load unit from two sides in a closed loop providing better compensation to the far-end consumers. Furthermore, the calculated voltage profile is much smoother as compared to the radial case with values closer to the nominal

380 V. The simulation results of transformer losses, line losses, voltage profile, and power factor for Zone A are shown in Figure 8.

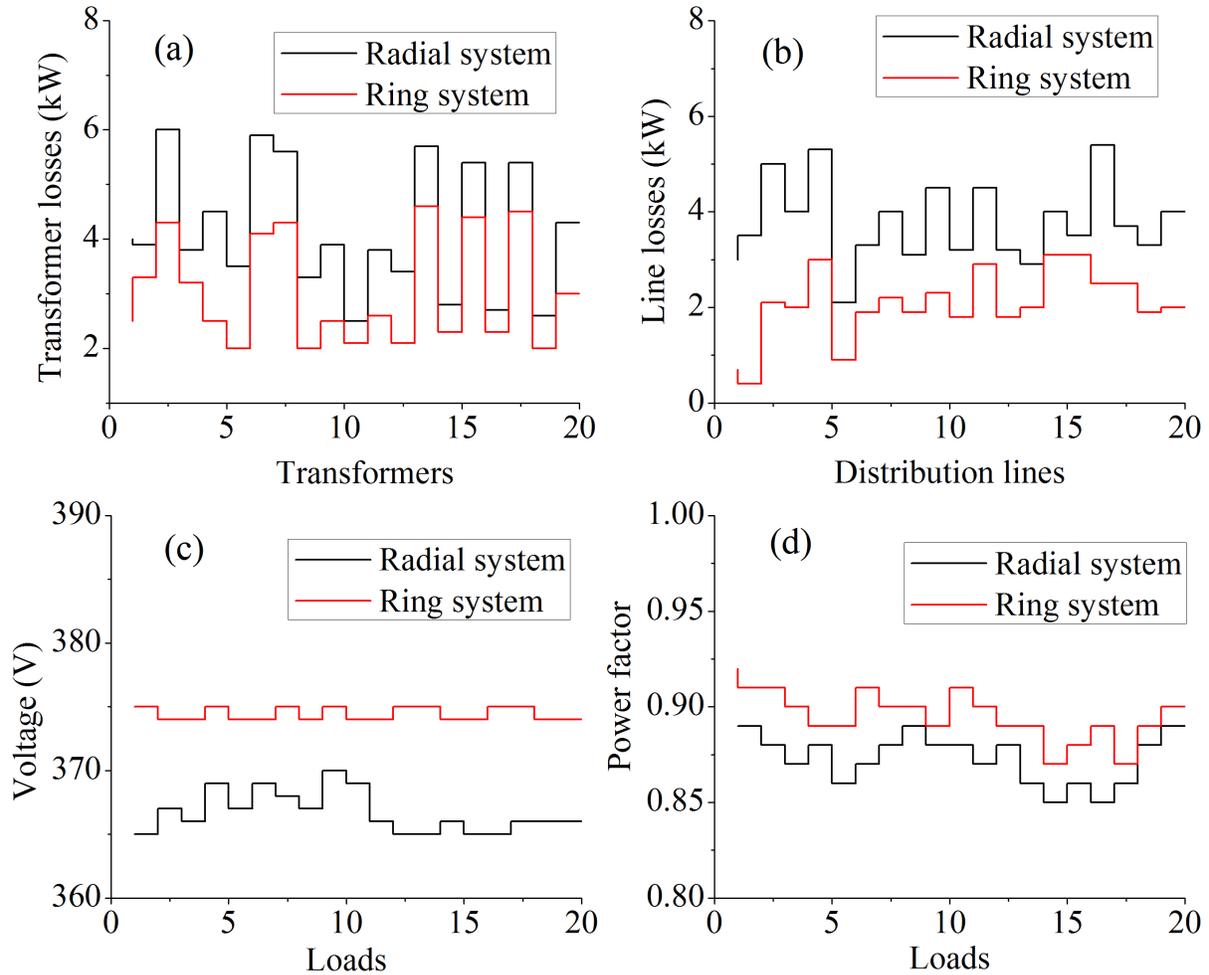


Figure 8. (a) Transformer losses, (b) line losses, (c) voltage profile, and (d) power factor in Zone A of the radial and ring distribution systems.

4.2. Zone B

The simulation results of all electrical quantities for Zone B of the radial and ring systems are shown in Figure 9. In Zone B, the minimum transformer loss is recorded as 2.3 kW for T17 and the maximum transformer loss is recorded as 5.9 kW for T3 in radial system. In the ring system counterpart, the minimum transformer loss of 2 kW occurs at T5, T15, T17, and T19 and the maximum loss of 3.4 kW occurs at T7. Line losses for radial system are minimum up to 2.9 kW at line20 and maximum up to 5.5 kW occurring at line8 in the radial system. For the ring system, the minimum value of line losses is 0.4 kW at line8 and 3.2 kW at line13. The voltage varies from 365 V to 370 V for the radial system and from 374 V to 375 V in the ring system, which are exactly the same as those recorded for Zone A. Finally, the power factor ranges from 0.85 to 0.89 for radial system and from 0.87 to 0.92 in the ring system which is also identical to the case of Zone A. Again, in Zone B,

the radial system exhibits higher transformer/line losses, poor voltage profile, and relatively low power factor as compared to the ring system.

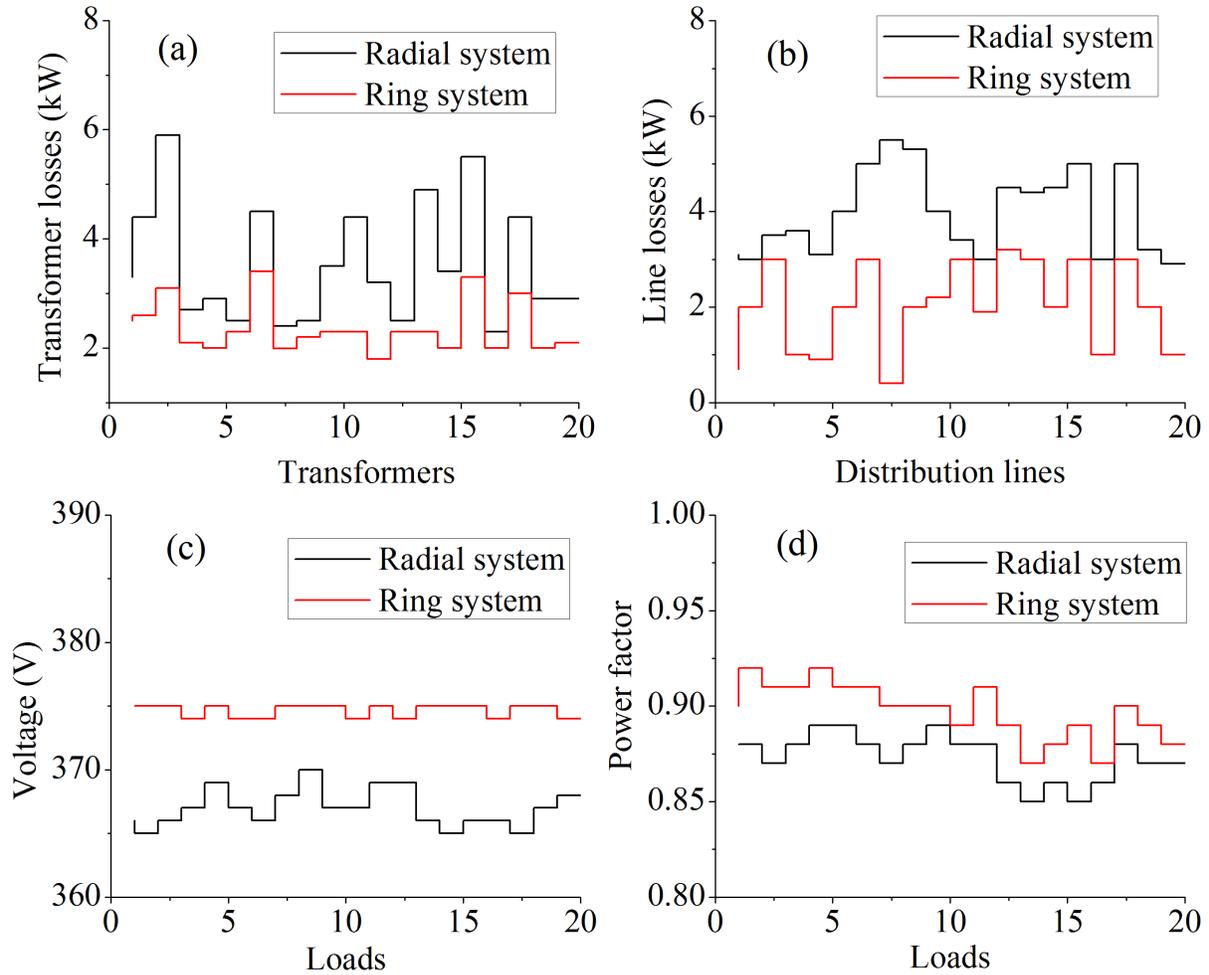


Figure 9. (a) Transformer losses, (b) line losses, (c) voltage profile, and (d) power factor in Zone B of the radial and ring distribution systems.

4.3. Zone C

In Zone C, the minimum transformer losses of 2.1 kW occur at T13, T15, and T17 and the maximum occurs at T3 with a value of 5.6 kW in the radial system simulation. In the ring system, the minimum transformer loss of 1.8 kW occurs at T13 and the maximum loss of 3.3 kW occurs at T1 as shown in Figure 10a. Line losses for the radial system are minimum up to 1.8 kW at line10 and maximum up to 3.2 kW occurring at line4 and line8. For Zone C of the ring system, the minimum value of line losses is 0.2 kW at line15 and the maximum value is 2.1 kW at line8 as shown in Figure 10b. The voltage varies from 365 V to 370 V for radial system and from 374 V to 375 V in the ring system. Finally, power factor ranges from 0.87 to 0.91 for the radial system and from 0.90 to 0.92 in the ring system. The voltage profiles and power factors for Zone C of radial and ring systems are shown in Figures 10c and 10d, respectively.

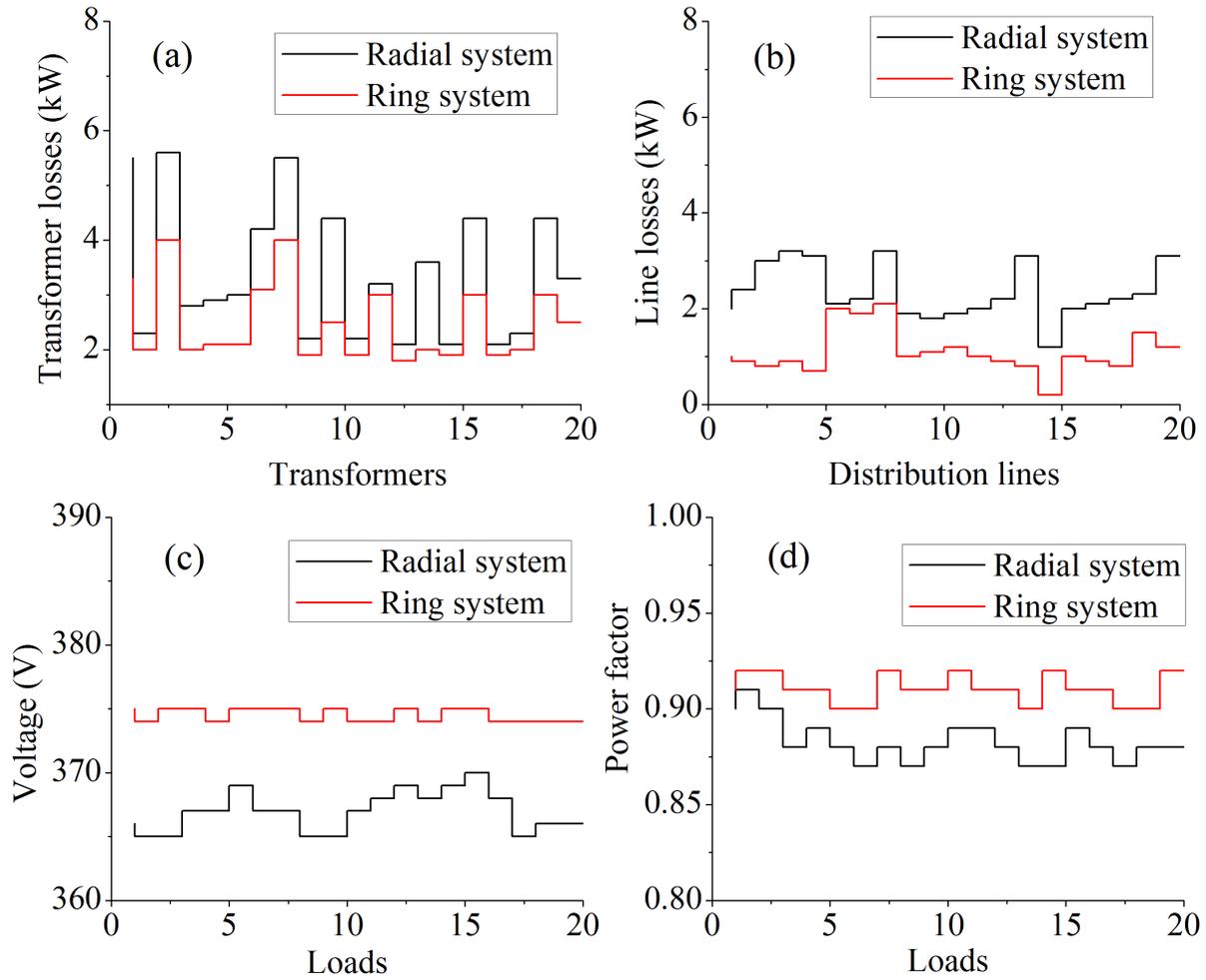


Figure 10. (a) Transformer losses, (b) line losses, (c) voltage profile, and (d) power factor in Zone C of the radial and ring distribution systems.

4.4. Zone D

Finally, in Zone D, the transformer losses range from 2.3 kW for T8 and T17 to 5.3 kW for T11 in the radial system simulation. In the ring system, the minimum transformer loss of 1.9 kW occurs at T5 and the maximum loss of 4.5 kW occurs at T19. Line losses for the radial system are minimum up to 1 kW at line10 and maximum up to 3.1 kW occurring at line3. For the ring system, the minimum value of line losses is 0.7 kW at line2 and the maximum value is recorded as 2.1 kW at line20. The voltage varies from 365 V to 369 V for the radial system and from 374 V to 375 V in the ring system. At last, the power factor ranges from 0.86 to 0.89 for radial system and from 0.88 to 0.91 in the ring system. As in all previous zones, the radial system exhibits higher transformer/line losses, poor voltage profile, and relatively low power factor as compared to the ring system. In addition, the voltage variation is recorded as having the same limits but the values at each load unit are different in all four zones. The results for Zone D are illustrated in Figure 11.

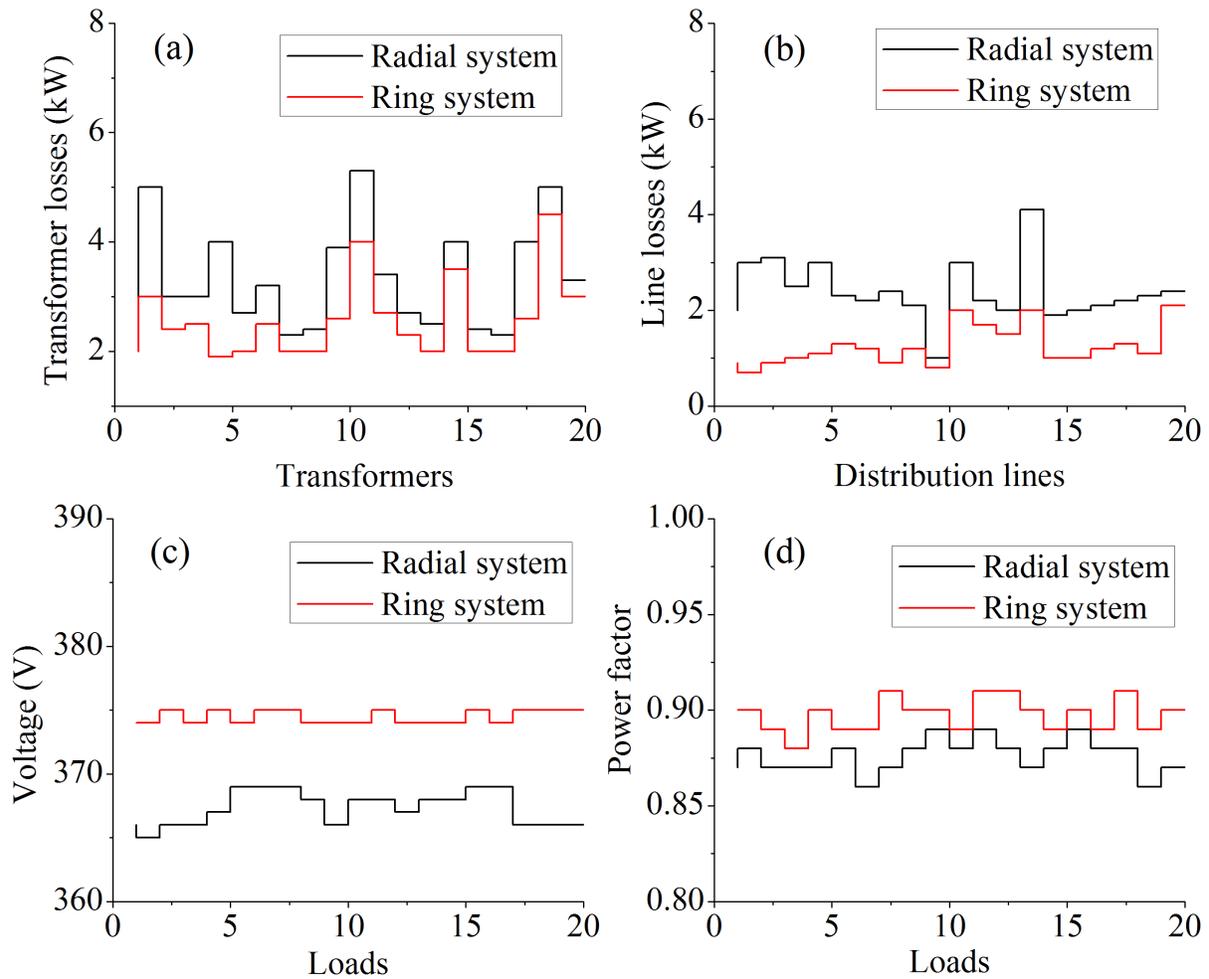


Figure 11. (a) Transformer losses, (b) line losses, (c) voltage profile, and (d) power factor in Zone D of the radial and ring distribution systems.

5. Conclusion

In this paper, power system planning is investigated in Kadhan Town of the Badin District, which is a rural area of Pakistan located in the southern part of Sindh Province. The district is surrounded by several big and industrial cities of Pakistan and is enriched by the most prominent renewable sources namely solar, wind, and biogas. Unfortunately, the town is a denizen of around 6000 families who are suffering in their lives due to the absence of electricity. In spite of the lack of attention from the provincial and local administration, an expedient and cost-effective solution is proposed for the well-being of the habitants of the region by all-renewable power distribution to the consumers.

The three renewable technologies were integrated at 11 kV grid from where the consumer lines are originating towards the load units. The simulation was carried out on ETAP software embedded with a power flow solver using different algorithms. The Newton–Raphson method was utilized in the performed simulations owing to its high success rate of convergence and fast approaching ability towards the solution. A survey was carried out in the initial phase of the research to estimate the total load, to constitute possible zones, to characterize the load units, and subsequently to evaluate transformer ratings. The survey data were fed to the

simulation software along with the information of correct ratings of the generators. For an estimated maximum load of 4.13 MW, three power plants (solar, wind, and biogas) of 2 MW output each were connected to the 11 kV grid. The selection criteria of these ratings were as follows: During day timing, the load is maximum so two generators, solar and wind, are capable to fulfill load requirement. If the load exceeds 4 MW, biogas generator of 2 MW rating will supply the deficiency in the generation. During night hours, the load is normally reduced to sometimes smaller than half of the maximum value, wind plant alone is utilized to fulfill the consumption. If the load exceeds the generation level, biogas plant is put into service making a total of 4 MW generation keeping in mind that the maximum load is 4.13 MW.

The load distribution scheme works in a reliable way ensuring continuous supply without surplus generation. However, the type of distribution is of paramount importance to evaluate quality of electricity and amount of losses. From the results of this research, it is concluded that the radial system implementation is simpler due to the requirement of only one generator bus connected to all consumer lines. The ring system requires five buses with one dedicated generator bus and four load buses connected in a closed manner creating a loop. The ratings of the components and load units are kept identical in both the architectures to draw a fair comparison which concludes that the ring system maintains superior results in terms of power factor, voltage levels, and losses.

Acknowledgment

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Author contributions

A.R.Y. gave the idea and performed the simulations. G.M. recorded the site data to be used in the simulations. M.A. and Z.R. interpreted the results. Z.R. wrote the paper.

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