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Distribution networks power loss allocation with various power factors

Debani Prasad Mishra[1], Rudranarayan Senapati[2], Arun Kumar Sahoo[1], Jayanta Kumar Sahu[1], Surender Reddy Salkuti[3]
[1]Department of Electrical and Electronics Engineering, IIIT Bhubaneswar, Odisha, India
[2]Department Electrical Engineering, KIIT Deemed to be University, Odisha, India
[3]Department of Railroad and Electrical Engineering, Woosong University, Daejeon, Republic of Korea

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ABSTRACT

The users of power distribution and transmission networks are generally guided to sustain advanced power factor (PF) of load as it is affecting the power loss of a feeder network where it separately owns major influence on electric charges layout. Therefore, some cautious loss allotment schemes are to be incorporated and an acceptable satisfying/penalizing policy for advanced/less PF users, independently. Keeping this in view, the mentioned article proposed a new scheme, i.e., the active power loss allocation (APLA) procedure which allows power loss to the system distributors by considering the load demands, topographical localities, and PFs. A newly modified procedure assigns inducements hardly to all the involved utilizers against change in load PF continuously, where it is evaluated via proper mathematical and statistical study. The efficiency of the newly modified APLA scheme is explored in two dissimilar frameworks of low PF using 33 bus system radially distributed network (RDN). The interpretation is in favor of examined transmitted, distributed, and allows generated PF to be verified subsequently. Comparatively, the results achieved highlight the originality of the present method compared with different standard schemes/frameworks.

Corresponding Author:

Surender Reddy Salkuti
Department of Railroad and Electrical Engineering, Woosong University
Jayang-Dong, Dong-Gu, Daejeon-34606, Republic of Korea
Email: surender@wsu.ac.kr

1. INTRODUCTION

This paper deals with how power loss is allocated within the buses. The proposed loss allocation method is used to reduce the loss in the system. The radial distributed network is considered with some methods by including forward and backward sweep-based methods and modeling it as a P-Q bus system the network is evaluated. In the current scenario, the power sector is losing its identity. So, to make the system most efficient and valued many more changes are defined and incorporated [1]. The rebuilding of the power unit sector represents different independent business units changed to power supply systems with a view of bringing competition among the service providers. This challenge is observed majorly in the areas of production i.e., generation, sending i.e., transmission, and distribution. In all the areas where the challenges are observed, power loss is playing a diverse part in the tax structure [2]. In the past, loss allocation [3]–[5] problems are forwarded to the transmission system, but due to day-to-day increases in sustained energy resources like solar energy, wind energy, and hydro energy [6], [7], distributed generations (DG) units [8]. Also, there will be more challenges for the allocation distribution systems) when compared with the power storing devices which will be added at the load ends. The addition of DG units has a major effect on the true power loss allotment [9] of radially distributed networks as it switches the current direction in the network. The power distribution system consists of different types of end users like household, industrial users, commercial consumers, and residential users too. The energy dissipated through them relies upon their power factors (PFs) of load [10] which defines the information about the load which is connected to radial distribution networks [11], [12]. Consequently, with extreme use of higher inductive loads [13] such as compressors, induction motors, and relays that use magnetic field, the quality of the loads gets decreased and simultaneously efficiency also gets reduced. Loads with low PFs increases losses in the whole system and efficiency get decreased. So, for accurate, productive, and effective operation of the power distribution system and service provider distributor has set some base value and standard PF value as 0.85 in India and 0.95 in the USA [14].

As most of the loads are highly inductive in nature, they cannot be avoided fully in PDS [15]. But we can improve the PF of this load by placing PF correction devices in our surroundings [16], [17]. The pro-rata method gives losses to the consumers as well as to DG owners according to their consumption of power [18]. This scheme allows power loss by ignoring the topographical areas of the utilisers, but the MW-mile technique [19] also known as the embedded cost pricing method has solved the problem by just multiplying the distances of the needed load points which are located near the substation bus by consideration of the ratings of consumers. Whereas the mentioned methods allocate losses excluding load flow [20] analysis. There is no disadvantage with the inclusion of a marginal loss coefficient (MLC)-based loss allotment scheme in which the losses are assigned to the system units according to their MLCs [21] derived from Newton-Raphson load flow analysis method [22].

2. FORMULATION OF PROPOSED LOSS ALLOCATION METHOD

The following area deals with the complete method of formulating the modified active power loss allocation (ALPA) method [23], [24]. For this method, the prerequisites are the converged values of the respective node voltages. These values are being derived by utilizing a forward and backward sweep-based [25] scheme as mentioned below. A suited index method is designed for the total flow of load and energy loss calculation [26]. In the mentioned method the slack/root bus of radially distributed network (RDN) is mentioned as '1', and subsequent buses with the main feeder and lateral feeders [27] are marked in their increasing order. The branch marking is conducted by reducing a single unit from its receiving end node number. Although the idea of negative load modeling (PQ type) [28] which is discussed is ensured to execute loss allocation in the presence of dispersed generation units. By taking negative load modeling of dispersed generation units into consideration, the total power injected at any of the node 'n' of the RDN can be estimated as,

$$P_{inj}^{n} + jQ_{inj}^{n} = \left(P_{load}^{n} - P_{dg}^{n}\right) + j\left(Q_{load}^{n} - Q_{dg}^{n}\right) \quad (1)$$

where $P_{inj}^{n} + jQ_{inj}^{n}$ is the complex load and $P_{dg}^{n} + jQ_{dg}^{n}$ is DG powers at bus-n. At any node 'n' having node voltage 'V^{n}_{nvlt}' the current of load or equivalent current injection (ECI) is calculated as,

$$ECI = \left[\frac{\left(P_{inj}^{n}+jQ_{inj}^{n}\right)}{V_{nvlt}^{n}}\right]^{*} = \frac{\left(P_{inj}^{n}-jQ_{inj}^{n}\right)}{\left(V_{nvlt}^{n}\right)^{*}}, \text{ for n=2, 3,…, n-bus} \quad (2)$$

by adding the equivalent current injection of the corresponding nodes and the current for any branch-bc can be found as,

$$I_{bcrt}^{bc} = \sum_{n\,\varepsilon SN(bc)} I_{neci}^{n} \quad (3)$$

the successive nodes related to any branch 'bc' of the network are stored in SN [ ] array. Thus (3) can be written/modified using (2) as,

$$I_{bcrt}^{bc} = \sum_{n\,\varepsilon SN(bc)} \frac{\left(P_{inj}^{bc,n}-jQ_{inj}^{bc,n}\right)}{\left(V_{nvlt}^{bc,n}\right)^{*}} \quad (4)$$

in words of branch impedance and branch current (I_{bcrt}^{bc}) the reactive power loss of the respective branch-bc can be calculated as,

$$S_{bloss}^{bc} = \{|I_{bcrt}^{bc}|^{2}\}\{Z_{bimp}^{bc}\} = \left[\left[\{I_{bcrt}^{bc}\}.\{I_{bcrt}^{bc}\}^{*}\right]\{Z_{bimp}^{bc}\}\right] \quad (5)$$

upon rearranging the (5),

$$S_{bloss}^{bc} = \{I_{bcrt}^{bc}\}^{*}\{Z_{bimp}^{bc}\}\{I_{bcrt}^{bc}\} \tag{6}$$

the branch current can also be expressed in the words of their sending and receiving end voltage and branch impedance. This is (7),

$$I_{bcrt}^{bc} = \frac{V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}}{Z_{bimp}^{bc}} \tag{7}$$

so, the (6) can be written as,

$$S_{bloss}^{bc} = \left\{\frac{V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}}{Z_{bimp}^{bc}}\right\}^{*} Z_{bimp}^{bc} I_{bcrt}^{bc} \quad = \left[V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}\right]^{*} \left[\frac{Z_{bimp}^{bc}}{\left(Z_{bimp}^{bc}\right)^{*}}\right] \left[I_{bcrt}^{bc}\right] \tag{8}$$

substitute the value of current in the branch from (4) in (8) as,

$$S_{bloss}^{bc} = \left[V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}\right]^{*} \left[\frac{Z_{bimp}^{bc}}{\left(Z_{bimp}^{bc}\right)^{*}}\right] \left[\sum_{n \varepsilon SN(bc)} \frac{\left(P_{inj}^{bc,n} - jQ_{inj}^{bc,n}\right)}{\left(V_{nvlt}^{bc,n}\right)^{*}}\right] \tag{9}$$

rearranging the (9),

$$S_{bloss}^{bc} = \sum_{n\ \varepsilon SN(bc)} \left[\left\{\frac{V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}}{V_{nvlt}^{bc,n}}\right\}^{*} \left\{\frac{Z_{bimp}^{bc}}{\left(Z_{bimp}^{bc}\right)^{*}}\right\}\right] \left[\left[P_{inj}^{bc,n} - jQ_{inj}^{bc,n}\right]\right] \tag{10}$$

$$\text{Let, } \left[\left\{\frac{V_{nvlt}^{bc,se} - V_{nvlt}^{bc,re}}{V_{nvlt}^{bc,n}}\right\}^{*} \left\{\frac{Z_{bimp}^{bc}}{\left(Z_{bimp}^{bc}\right)^{*}}\right\}\right] = A_{nrel}^{bc,n} + jB_{nimg}^{bc,n} \tag{11}$$

therefore, the reactive power loss within the branch-bc can be calculated and it is shown as,

$$S_{bloss}^{bc} = \sum_{n\ \varepsilon SN(bc)} \left\{A_{nrel}^{bc,n} + jB_{nimg}^{bc,n}\right\}\left\{P_{inj}^{bc,n} - jQ_{inj}^{bc,n}\right\} \tag{12}$$

$$S_{bloss}^{bc} = \sum_{n\ \varepsilon SN(bc)} \left\{A_{nrel}^{bc,n} P_{inj}^{bc,n} + B_{nimg}^{bc,n} Q_{inj}^{bc,n}\right\} + j\left\{B_{nimg}^{bc,n} P_{inj}^{bc,n} - A_{nrel}^{bc,n} Q_{inj}^{bc,n}\right\} \tag{13}$$

$$S_{bloss}^{bc} = P_{bloss}^{bc} + jQ_{bloss}^{bc} \tag{14}$$

therefore, the true power within the branch-bc can be formulated in (15).

$$P_{loss}^{bc} = \mathfrak{R}\left\{S_{bloss}^{bc}\right\} = \sum_{n\ \varepsilon SN(bc)} \left\{A_{nrel}^{bc,n} P_{inj}^{bc,n} + B_{nimg}^{bc,n} Q_{inj}^{bc,n}\right\} \tag{15}$$

From (15), it can be stated that the reason for the true power loss of the concentrated branch is the load points that are present beyond branch-bc. Therefore, to evaluate their own contribution, calculated energy loss to be assigned within the utilisers, i.e., $n\ \varepsilon SN(bc)$. Hence, the true power also called the active power loss allotted to the subsequent utiliser at node 'n', out of the total active power loss of branch 'bc' can be calculated as:

$$P_{nloss}^{bc,n} = A_{nrel}^{bc,n} P_{inj}^{bc,n} + B_{nimg}^{bc,n} Q_{inj}^{bc,n} \tag{16}$$

hence, by appending the single contribution regarding the real energy loss in each branch in the RDN [11] the overall active power loss (APL) which is allotted at the end which is connected at the 'n^{th}' node is calculated as:

$$P_{nloss}^{n} = \sum_{bc=1}^{nb-1} P_{nloss}^{bc,n} \tag{17}$$

therefore, the total true energy drops of the RDN [11] is calculated by adding individual energy drops of the utilisers respectively that are available in the network as (18).

$$P_{tloss}^{RDN} = \sum_{n=1}^{nb} P_{nloss}^{n} \tag{18}$$

3. RESULTS AND DISCUSSION

In the following part, the advantage of the modified loss allocation [3] method is verified. It is verified by changing LPF and by executing a case study. A 12.66 kV 33-bus radial distribution network [11] with thirtytwo branches is observed and is observed for examining the methods and results of the present procedure in a case study. The related data for the case study are considered from the standard IEEE values. The PF of the consumers (PF_{conj}^{n}) can be calculated from the load data (P_{load}^{n} and Q_{load}^{n}) from standard values using (19).

$$PF_{conj}^{n} = \cos\left(tan^{-1}\frac{P_{load}^{n}}{Q_{load}^{n}}\right) \quad (19)$$

The results obtained from (19) represents the PF at the base case condition [4]. The results obtained in PF calculations are classified into three groups based on their decreasing PF; firstly, the subgroup group 1 (SG-1) consists of the first five buses, secondly, the subgroup 2 (SG-2) has the last 5 buses and the third group consists of the remaining buses. The performance analysis of the 33-bus network is carried out considering two scenarios based on the discussion in [11]. In situation 1, the load PFs of sub subgroup 1 (SG1) and subgroup 3 (SG3) will be reduced and increased by 10% respectively where the values of G2 remain constant. In scenario II, the load PFs of subgroup 1 (SG1) and subgroup3 (SG3) have decreased and increased by 20% respectively while the values of SG2 remain constant.

In this case study, a thirty-three-bus radial distributed network [11] with a full load consisting of (3715+j2300) kVA and a rating of 12.66 kV is considered while the consequent load data, and the line data has been provided in IEEE standard values. From the loss allocation comparative values, it is observed the whole network has a total true power loss at base case, situation-I, and situation-II of 202.67 kW, 198.06 kW, and 190.53 kW respectively. Therefore, to verify the execution of the network, the consumers of the network are divided into three groups as discussed previously in [11]. The detailed divided groups' data of 33-bus is provided along with the variation of PF in two different situations. So, the PF modifies as per the discussion in [11] for two situations mentioned below for calculating the loss. Further, the power loss is varied for different PF. The 33-bus test system is divided into sub-groups as SG1 having node numbers 6, 9, 10, 15, 16, and sub SG2 having node numbers 4, 11, 14, 30, 33, and SG3 having node numbers 2, 3, 5, 7, 8, 12, 13, 17, to 29, 31 and 32. In this paper, the PF is changed in two situations, i.e., in the situation I, we increase and decrease the PF by 15% and by 25% for SG1 and SG2 respectively. For SG3 the PF remains constant in both situations. As the PF is inversely proportional to power loss and the below values are calculated based on this condition. Variation of power loss for different PFs is depicted in Table 1.

Table 1. Variation of power loss for different power factors

Node No	Actual power factor	Power loss	Power loss at various power factor				
			pf=1.0	pf=0.9	pf=0.85	pf=0.82	pf=0.7
2	0.8575	0.30	0.25725	0.28583	0.30264	0.3137	0.3675
3	0.9138	1.39	1.2701	1.47113	1.49433	1.5490	1.8145
4	0.8320	3.25	2.704	3.0044	3.1811	3.2975	3.8625
5	0.8945	1.83	1.6369	1.8188	1.925	1.9962	2.3384
6	0.8320	2.22	1.8470	2.0522	2.1729	2.2524	2.6386
7	0.8944	9.47	8.4699	9.4110	9.9646	10.329	12.099
8	0.8944	10.62	9.498	10.5539	11.174	11.583	13.569
9	0.8320	2.95	2.4544	2.72711	2.8875	2.9931	3.5062
10	0.8320	3.27	2.7206	3.02293	3.2007	3.3178	3.886
11	0.8320	3.55	2.9536	3.2817	3.4748	3.6019	4.2194
12	0.8638	4.50	3.8871	4.319	4.5730	4.7403	5.553
13	0.8638	4.94	4.2671	4.741	5.020	5.2038	6.095
14	0.8321	11.00	9.1531	10.1701	10.7683	11.1623	13.075
15	0.9864	1.83	1.805	2.0056	2.123	2.2013	2.578
16	0.9487	4.04	3.832	4.2586	4.5091	4.674	5.4753
17	0.9487	4.14	3.927	4.364	4.6207	4.789	5.6108
18	0.9138	7.15	6.533	7.2596	7.6866	7.6978	9.3338
19	0.9138	0.28	0.255	0.2842	0.3010	0.3120	0.36552
20	0.9138	0.55	0.502	0.5584	0.5912	0.6129	0.7179
21	0.9138	0.61	0.5574	0.6193	0.6557	0.6797	0.7963
22	0.9138	0.65	0.5939	0.6599	0.6987	0.7243	0.8485
23	0.8742	1.87	1.6347	1.8163	1.9232	1.9936	2.335
24	0.9029	10.78	9.733	10.78	11.4508	11.8698	13.9046
25	0.9029	12.11	10.934	12.149	12.863	13.334	15.620
26	0.9231	2.56	2.3631	2.6257	2.7801	2.8818	3.3759
27	0.9231	2.68	2.473	2.7487	2.9104	3.0169	3.5341
28	0.9487	2.69	2.835	2.750	2.523	2.2683	2.0131
29	0.8638	8.05	6.953	7.7262	8.1806	8.4799	9.9337
30	0.3162	5.31	1.6790	1.8655	1.9753	2.0475	2.3986
31	0.9062	9.76	10.77	10.44	9.585	8.616	7.6468
32	0.9029	14.01	12.695	14.10	14.9363	15.482	18.136
33	0.8321	5.01	4.168	4.6320	4.9044	5.0839	5.9554

4. SIMULATION RESULTS

Variations of power loss among base case, situations I and II are depicted in Figure 1. In Figure 1, it is seen that the power loss is extremely high at node 30 when compared to other nodes of the network due to high impedance. From Table 1, it is observed the energy loss is decreased at some nodes i.e., for SG1 nodes, and increased at some nodes i.e., for SG2 nodes while at some nodes i.e., for SG3 nodes the power loss doesn't vary.

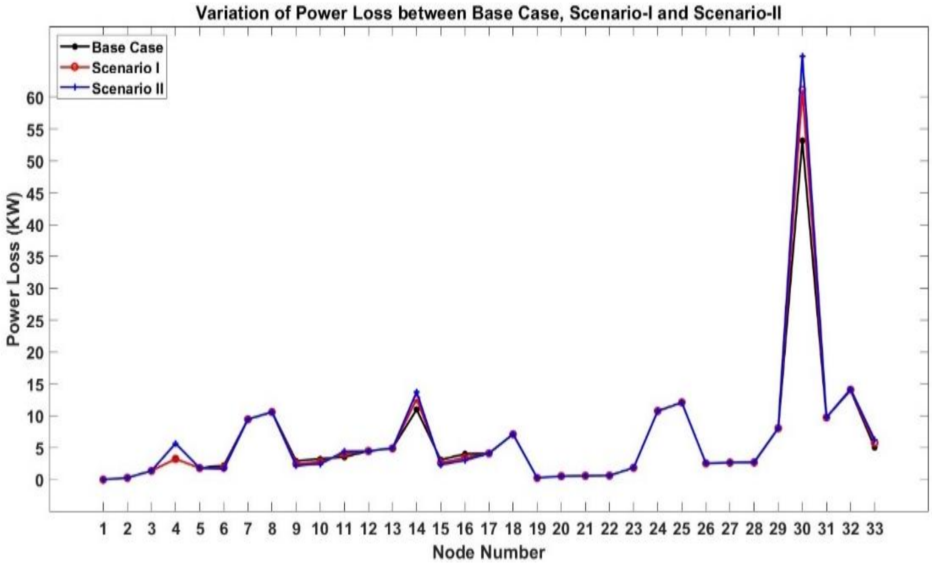

Figure 1. Variation of power loss among base case, situations I and II

In Figure 2, it is seen that pf is extremely low at node 30 when compared to other nodes of the network. It is observed that the PF is decreased at some nodes, i.e., for G1 nodes, and increased at some particular nodes, i.e., for G2 nodes while at some nodes, i.e., for G3 nodes the power loss doesn't vary. In Figure 3, it is observed that the value of power loss varies differently for different PFs. In the above bar graph, the power loss at base condition is varied with PF like when its value is 1.0, 0.9, 0.85, 0.82, and 0.7. For all the mentioned cases of PF, the power loss is calculated. It is observed that at 32 buses there is high power loss due to high reactance at that particular bus.

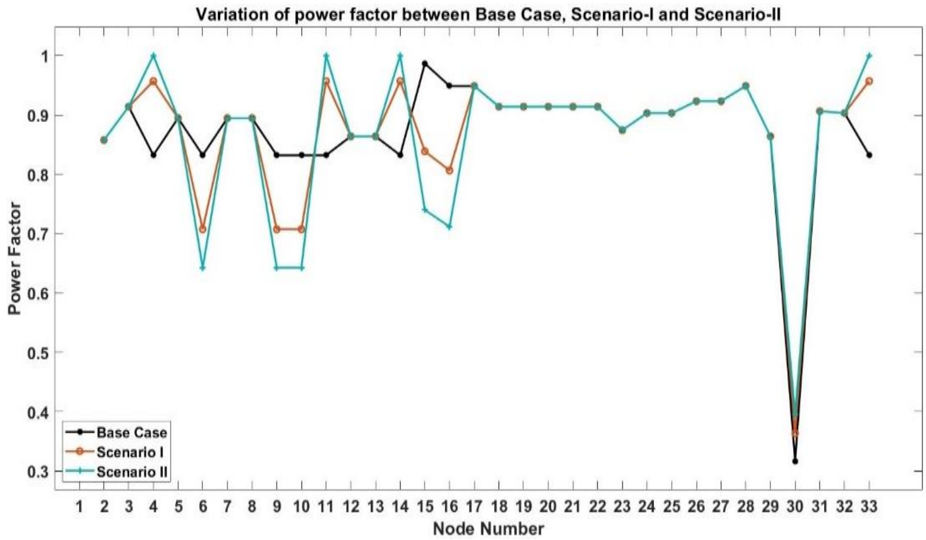

Figure 2. Variation of power factor for base case, scenarios I and II

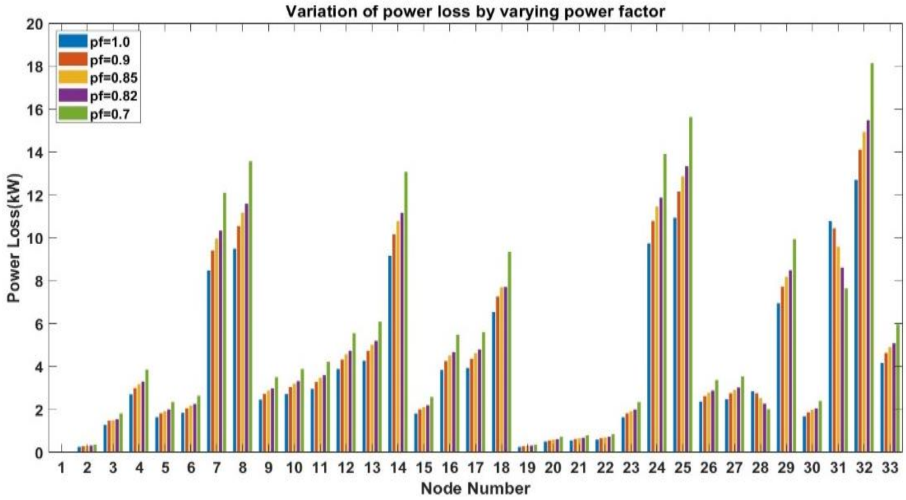

Figure 3. Variation of power loss with varying power factors

5. CONCLUSIONS

The proposed method for the true power loss allotment method is explained and represented in the paper, in which it is working efficiently and adequately by considering load or DG power factors variation. The proposed method is considered the best method for loss allocations due to the following considerations. The methodology, formulation, and terms of these methods are quite easy and understandable. The results in loss allocation are found to be satisfactory despite variations of the power factor of corresponding load i.e., it allotted higher losses to respective mentioned load points in which the power factor is decreased and lesser losses to those in which it is improved unless placing it unchanged for the remaining. Keeping in view of distribution in loss allocation, it is discussed and figured that the modified scheme is very experimental and sensible. From the above methods, it can be concluded that the evolved methods or algorithms meet all the obligations or demands of the loss allocation method without any complications. The method results provide a good voltage profile, i.e., whenever there is a change in load the system voltage level also changes accordingly.

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BIOGRAPHIES OF AUTHORS

Debani Prasad Mishra received the B.Tech. in electrical engineering from the Biju Patnaik University of Technology, Odisha, India, in 2006 and the M.Tech. in power systems from IIT, Delhi, India in 2010. He has been awarded a Ph.D. degree in power systems from Veer Surendra Sai University of Technology, Odisha, India, in 2019. He is currently serving as assistant professor in the department of electrical engineering, IIIT Bhubaneswar, Odisha. His research interests include soft Computing techniques application in power systems, signal processing, and power quality. He can be contacted at email: debani@iiit-bh.ac.in.

Rudranarayan Senapati received the B.Tech. in electrical engineering from the Utkal University, Odisha, India, in 2001 and the M.Tech. in communication system engineering in 2008 from KIIT University, Odisha. He has been awarded a Ph.D. degree in electrical engineering from KIIT deemed to be University, Patia Bhubaneswar, Odisha, India, in 2018. He is currently serving as assistant professor in the school of electrical Engineering, KIIT, deemed to be University, Patia, Bhubaneswar, Odisha. His research interests include Solar forecasting, blockchain technology, renewable integration to power systems, and power quality. He can be contacted at email: rsenapatifel@kiit.ac.in.

Arun Kumar Sahoo completed Ph.D. from IIIT Bhubaneswar in the department of electrical engineering, ODISHA, India in 2021. He completed the M.Tech. degree in energy system and management from the SOA University, Odisha, India in 2013. His research interests include power system economics, micro-grid, and soft computing applications to power system, optimal power flow. He can be contacted at email: C116003@iiit-bh.ac.in.

Jayanta Kumar Sahu received the B.Tech. degree in electrical and electronics engineering from the Biju Patnaik University of Technology, Odisha, India, in 2010 and the M.Tech. in power systems from Biju Patnaik University of Technology, Odisha, India in 2014. He is currently serving as assistant professor in the department of electrical engineering, International Institute of information technology Bhubaneswar, Odisha. His research interests include renewable energy, electrical machine, and power electronics. He can be contacted at email: jayanta@iiit-bh.ac.in.

Surender Reddy Salkuti received the Ph.D. degree in electrical engineering from the Indian Institute of Technology, New Delhi, India, in 2013. He was a postdoctoral researcher at Howard University, Washington, DC, USA, from 2013 to 2014. He is currently an associate professor with the department of railroad and electrical engineering, Woosong University, Daejeon, South Korea. His current research interests include market clearing, including renewable energy sources, demand response, smart grid development with integration of wind, and solar photovoltaic energy sources. He can be contacted at email: surender@wsu.ac.kr.