Effective Loss Minimization and Allocation of Unbalanced Distribution Network

Manvir Kaur * and Smarajit Ghosh

Department of Electrical and Instrumentation Engineering, Thapar University, Patiala 147004, Punjab, India; smarajitg@hotmail.com
*   Correspondence: manvir_kaur@thapar.edu; Tel.: +91-988-848-3123

Abstract: An efficient distribution network must be able to supply power with good voltage profile. The main objective of the proposed work is to allocate losses of the unbalanced distribution network by the firefly algorithm in regulated and deregulated environments before and after loss minimization. Reconfiguration is one of the methods for loss reduction of unbalanced distribution network. Further, optimal placement of distributed generation and capacitor in the reconfigured unbalanced distribution network can further reduce the loss. The results of reconfigured unbalanced distribution network in regulated environment have already been reported. In this paper reconfiguration of an unbalanced distribution network in a deregulated environment is also carried out using an established Fuzzy Firefly algorithm. Loss sensitivity factor of unbalanced distribution networks is used to get the appropriate location of distributed generation and capacitor to be placed in the unbalanced distribution network. Their ratings have been found out by using bacteria foraging optimization algorithm (BFOA). The suggested loss allocation method using Firefly algorithm is implemented at first on 13 node unbalanced distribution network to check the performance of the proposed loss allocation method when compared to other available method. Finally the proposed method has been implemented on 25 node unbalanced distribution network. Both of the implementations are carried out under MATLAB environment.

Keywords: network reconfiguration; distributed generation; capacitor; loss allocation; fuzzy logic; bacteria foraging optimization algorithm (BFOA); firefly algorithm

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1. Introduction

In a regulated environment, the customers have to pay the set price as established by the utility company. In this environment the power flow from the generation to consumer meter is entirely controlled by the vertically integrated utility. Recently, the power system has encountered real changes and has also been operating in a deregulated environment. The vertically coordinated systems are being rebuilt and unbundled into generation, transmission, and distribution entities. In this environment, customers will get reliable services, more choices, and need to pay less amounts for the consumption of electricity in the competitive market. In addition to these, privatization and functional separation of existing power system entities are the stands behind the causes of the deregulated power industry [1]. In this new environment, the traditional centralized system is lost and leads to the formation of new companies participating in the generation. This made the generating companies more dependent on decision-making tools for the analysis of all the possible investment and selling options in the present competitive environment [2].

Traditional unified power system networks are taking energy from high voltage (HV) levels and sending it to low voltage (LV) level distribution network (DN), but in the era of the deregulated environment, there will be a need of lively distribution network management, from central to many

distribution networks. In this kind of network, there will be more distributed generations (DG's) in the system along with latest advanced ideas [3]. Along these lines, overhead distribution frameworks are fundamentally arranged in a radial way to make simple inherent components of the system assurance, for example, coordination and lessening of short out streams and decreasing hardware costs [4]. Low adaptability and dependability for the functioning of radial distribution networks (RDNs) cause those frameworks to be developed through the sectionalizing switches (SS) [5]. By varying the condition of the SS, i.e., opening or closing, the network is being reconfigured, and the function of the network is also enhanced [6]. Modification in the topology of any distribution network reduces the system's loss, enhances the system's voltage profile (VP), and restores the power supply. Along these lines, SS are utilized for fault segregation in addition to the reconfiguration [7,8].

These days, distribution networks that are being affected by expanding the addition of DGs, which are constantly utilized as a part of the transmission network [9]. Hereafter, DG got to be one of the applicable parameters in the assessment of network reconfiguration [10]. The incorporation of DG in any distribution network influences the operation of this DN in different courses [11]. An intriguing issue that is identified with DG is the loss allocation (LA) issue, which turns out to be essential to the presentation of utility rivalry [12].

Section 2 provides some of the recent research works done in this field. Section 3 describes the suggested technique, and Section 4 shows the simulated outcomes using the proposed technique along with discussion. Finally, in Section 5, the results are concluded, followed by references.

2. Related Works

Oliveira et al. [13] had presented a simulator based on the graphic for DNs with network reconfiguration and earmark of losses applications. They used current summation backward-forward technique taking into account DG to form a power flow algorithm for solving reconfiguration problem. They implemented and did a comparison of four LA methods, which were "Zbus, Direct Loss Coefficient, Substitution and Marginal Loss Coefficient" on a 32 bus system. From the comparison of these methods, it was found that the Zbus method had a better performance and was simple to implement, while "Substitution and Marginal Loss Coefficient methods" required an adjustment factor.

Savier and Das [14] proposed an LA technique for the deregulated environment before and after reconfiguration. The method was formed in a quadratic way and stood on the determination of two different parts of current in each branch. The suggested algorithm was based on multi-objective optimization in a fuzzy environment. For this, three objectives were examined and were modelled in a fuzzy framework. The 69 node balanced test system results revealed that there was a reduction in real power losses with reconfiguration and LA to most of the consumers were reduced, but it was also observed that LA to some consumers may increase, resulting in more payment after reconfiguration. From these observations, they found that the allocation of real power loss to each consumer was affected by the objectives that were considered for network reconfiguration.

Chandramohan et al. [15] suggested a technique for minimizing the operating cost of balanced RDNs in a deregulated environment. They reconfigured the network using "non-dominated sorting genetic algorithm (NSGA)". They minimized the operating cost and maximized the operating reliability so that the operating constraints were satisfied. They used the related formulas available in literature. They tested their method on balanced 33 node and 69 node RDNs.

Atanasovski and Taleski [16] had proposed a "Power Summation Method" to allocate loss in RDNs with DG. The suggested approach is branch oriented, which was formed from the backward sweep power summation method without any kind of approximations and assumptions. They treated active and reactive loads as positive, and DGs were representing negative loads. They decomposed the branch losses to node related components, which made their suggested method simple and efficient for DN. The suggested method is applied to balanced 32 node RDN and results were correlated with the "Branch Current Decomposition Loss Allocation (BCDLA)" method and "Marginal Loss Coefficients (MLC)" method.

Savier and Das [17] had given a method to allocate real power loss in RDN in a deregulated environment. They compared their suggested "Exact Method" with two algorithms that are available in the literature; first was depended on each consumer load demand called "Pro rata algorithm" and second was "Quadratic loss allocation" scheme, those identified the two different components of current in each branch. LA to each consumer was carried out and the suggested method was tested on balanced 30 node RDN.

Ghofrani-Jahromi et al. [18] had presented an LA technique in RDNs depending on the outcomes of power flow and considering the active and reactive power flow through the lines. They considered three steps. The power loss designated to all of the nodes starting from the nodes having generation greater than their load computed in the earlier step. At the same time, the power loss that is designated to the loads associated with each node is achieved. In the next step, the LA starts from the sink nodes, i.e., nodes having a load greater than their generation. In the last step, the execution of normalization was done. Their suggested method was tested taking 17 node and 69 node RDNs.

Jagtap and Khatod [19] had offered a method for LA to DGs and consumers those who were associated with RDNs in the emancipated market. The prime motives of that paper were focused on the nonlinear alliance between the flow of power and losses, revisions of system losses due to the variation of voltage, and benefaction of DG to system's loss. The technique presented in [13] had been used in LA. The application of the method was once again limited to 28 node and 33 node balanced RDNs.

Jagtap and Khatod [20] had proposed a technique for the LA in balanced RDNs using diverse models of DG and loads in a deregulated environment. Without assuming and approximating anything, they derived a straight relation between active and reactive power flow and its losses. "Power summation algorithm" (PSA) was used to derive approximate expressions/relations for power flow of network and any cross term was avoided. A network dependent branch oriented technique was used to allocate the losses among the members of the network. The LA to any DG/load at different nodes was carried out using backward sweep network diminution algorithm. The LA in two different RDNs (nine node and 33 node) had been performed in the presence of different types of DG and load models.

Sharma and Abhyankar [21] presented an efficient method of loss allocation with Shapley value and network laws. They had provided a solution with a cooperative game theory approach. They used Shapley value for balanced radial and weekly meshed distribution system to solve the analytical solution provided by the proposed method. They used the network data and power flow solutions without any assumptions in their proposed method. They had given the results with different setups of network topologies, DG output levels rivalled their result by two other Shapely value based balanced test systems. They had shown that the Shapely value based LA had given the best result in comparison to the other methods reported.

Kaur and Ghosh [22] presented a method to reconfigure unbalanced distribution networks (UDNs) in the fuzzy environment using the Firefly algorithm in a regulated environment. They also suggested a load flow method for the solution of UDNs. They had also rigorously discussed different available methods of reconfiguration in a deregulated environment. Their suggested method was tested on 19 and 25 node UDNs. The concluded results were compared with the outcomes attained by "Genetic algorithm (GA), Artificial Bee Colony (ABC) algorithm, Particle Swarm Optimization (PSO) algorithm and Genetic algorithm-Particle Swarm Optimization (GA-PSO) algorithm", keeping the objective function unaltered.

3. Proposed Methodology for Network Reconfiguration and LA in UDN

The formations of UDNs might be changed with manual or programmed switching application in order to decrease power loss, expand network security, and improve power quality. Despite the fact that the principal mission of network reconfiguration is to decline the losses of the system in a deregulated environment, the reconfiguration deliberates the objectives that are identified with

expanding the benefits of an organization, for example, operational cost minimization and reliability maximization. Likewise, in the deregulated environment, the losses are assigned to various purchasers in the network. In this work, the effect of network reconfiguration, the integration of DG and capacitor in the reconfigured network, and the impact of LA in UDNs in both the regulated and deregulated environments are presented. The network reconfiguration problem is defined as a fuzzy based multi-objective problem. For optimization of the network, the Firefly optimization algorithm is utilized, which augments the fuzzy based objective function. The proposed formulation of problem considers the accompanying viewpoints:

- LA of 13 node UDN and comparison of outcomes obtained by proposed method and that of by [12].
- LA of base network (25 node UDN) and its reconfigured network in regulated environment.
- DG and capacitor have been placed in reconfigured network using Loss Sensitivity Factor (LSF) and Bacteria foraging optimization algorithm (BFOA).
- LA of the network after placement of DG and capacitor.

The above steps are also carried for deregulated environment. Network reconfiguration in the deregulated environment using the established Fuzzy-Firefly algorithm [22] is carried out. The details of Firefly algorithm are available in [22]. The well-established optimization equations available in [23–25] used by [15] also have been used in unbalanced systems incorporating suitable changes. The same optimization algorithm i.e., Firefly has been used to obtain loss allocation.

3.1. LA in UDN

The three phase currents are recognized by $\bar{I}_a$, $\bar{I}_b$ and $\bar{I}_c$, however, $\bar{I}_n$ is the neutral current. For the purpose of notation, the vector $i = \begin{bmatrix} \bar{I}_a & \bar{I}_b & \bar{I}_c \end{bmatrix}^T$ is the phase current vector, and the vector $v_k = \begin{bmatrix} \bar{V}_{k,a} & \bar{V}_{k,b} & \bar{V}_{k,c} \end{bmatrix}$ includes the complex voltages in the phase terminals of the genetic node k. The total losses can be computed as the sum of losses due to each physical current path

$$\Delta P_{Total} = R_a I_a^2 + R_a I_b^2 + R_a I_c^2 + R_n I_n^2 \tag{1}$$

Or utilizing the 4×4 primitive impedance matrix Z_{prim}.

$$\Delta P_{Total} = \text{Re}al\left\{ \begin{bmatrix} \bar{I}_a & \bar{I}_b & \bar{I}_c & \bar{I}_n \end{bmatrix} Z_{prim} \begin{bmatrix} \bar{I}_a^* \\ \bar{I}_b^* \\ \bar{I}_c^* \\ \bar{I}_n^* \end{bmatrix} \right\}. \tag{2}$$

Or utilizing the 3×3 primitive impedance matrix Z_{abc}

$$\Delta P_{Total} = \text{Re}al\left\{ i^T Z_{abc} i^* \right\} \tag{3}$$

According to the impedances matrix symmetry, Equation (2) can be altered applying the real part operator only to the impedance in order to extract its resistive components. So, the overall branch losses can be computed through the real part of impedance matrix Z_{abc}.

$$R_{abc} = \text{Re}al\{Z_{abc}\} \tag{4}$$

$$\Delta P_{Total} = i^T \text{Re}al\{Z_{abc}\} i^* = i^T R_{abc} i^* \tag{5}$$

The formulation of Equation (2) leads to the loss partitioning. Here, it is suggested to estimate the loss partitioning by utilizing Equation (5). By representing with $\otimes$ the component by-component vector product, the loss partition vector $\Delta p = \begin{bmatrix} \Delta P_a & \Delta P_b & \Delta P_c \end{bmatrix}$ denoted to three phases *a*, *b*, and *c* in the equivalent 3×3 matrix representation of the branch is considered as

$$\Delta p = \text{Re}al\{i \otimes (R_{abc} i^*)\} \tag{6}$$

The total loss ΔP_{Total} in Equation (5) corresponds to the sum of the components of the vector Δp. The real part operator is required in Equation (6) because of the effect of the off-diagonal components of the matrix R_{abc}. It is no longer needed in Equation (5), as all of the imaginary parts are mutually compensated in the sum.

3.2. Network Reconfiguration of UDN in Deregulated Environment

Any UDN consists of two types of switch, known as normally open switch (tie-line switch) and normally closed switch (sectionalizing switch). By closing the tie-line switches and opening sectionalizing switches, the arrangement of the distribution network can be modified. The loss minimization may not be optimal with the opening and closing of improper switches. Hence, the selection of switches is most vital to get the optimal network, which gives a maximum loss reduction and superior VP. Any predetermined reason identifies the function of a specific configuration. For example, a configuration with maximum loss reduction and superior VP is always expected. The aim to reconfigure any network is to reduce loss, expand reliability indices, use of a maximum number of switches, and cut down the working cost of the system. The intelligent algorithm can be used to compute the objective function having multiple variables. The consequence of any objective can be determined by the weighting elements. It is not required to install any additional instruments to take care of network issues; those can be solely done by reconfiguring the network. Any network having 'n' number of open or closed switches will have '$2n$' number of arrangements. Hence, it is not feasible to think about all states of reconfiguring the network. During reconfiguring the network, the following limitations are considered:

- All of the network buses must be limited.
- Summation of net load and net losses must tally with the generation and should be neither equal nor exceed the capacity of the network.
- The final structure of the network must be radial.
- Bus voltages should be within the limits.

The reconfiguration problem becomes a complex optimization problem due to its huge solution space and a number of constraints. The cost of the network in the deregulated environment should be paid the highest attention in comparison to any general network in the regulated environment, and hence the objective function in a deregulated environment becomes entirely different. This paper considers multi-objective optimization for reconfiguring the network. In this proposed methodology, for the case of reconfiguration in a regulated environment, reducing the power loss, reducing the bus voltage deviance, and load equalizing done by the feeders are considered as the objectives and fuzzified, as mentioned in [22]. The objective function for network reconfiguration in a regulated environment is available in [22] and presented below.

$$\lambda F_m = \left(\lambda P_{L_m} \times \lambda V_m \times \lambda I_m\right)^{\frac{1}{3}} \tag{7}$$

The fitness function is deliberated in Equation (7) is maximized during the optimization procedure to acquire the best well-matched configuration. This operator has numerous benefits. For instance, if any membership function of each objective reaches the value of zero, λF_m is allocated to a value of zero. Additionally, this function delivers correct information as about how making this algorithm achieving an ideal state, namely a value of 1. This objective function is utilized as the fitness function. As the network cost is more significant in the case of the deregulated environment when compared to the traditional network, the deregulated environment has a different objective function. In the deregulated environment, the main objective is to improve the benefits for the company. Here, two objectives are considered for the deregulated environment, such as operational cost minimization and reliability maximization.

In this work, the fireflies move with the values of $\beta = 1$, $\gamma = 0.75$, and $\alpha = 0.25$ are considered where β, γ, and α are the intensity or attractiveness of the firefly's flashing light, light absorption coefficient of a given medium, and randomization parameter, $\alpha \in [0, 1]$. The number of firefly population is taken as 100 and the maximum number of iterations is selected as 150.

3.3. Minimization of Operational Cost

There are two parts of the net operating cost. The cost due to real power loss is considered as operation cost at first that can be reduced by reducing the losses in the distribution network. The cost due to real power loss is equal to $A_1 \times P_S$, where A_1 is the coefficient for the price of real power and its unit is \$/kW and a net loss of system's active power (P_S) in kW. The second component is the reactive power cost, as procured with the distribution network. The cost component can be decreased if the system's reactive power loss is decreased. The second component is represented by $A_2 \times Q_S$, where A_2 represents the coefficient of price in \$/kVAr and Q_S represents the reactive power that is consumed by the distribution network from the transmission system connected to it. The Operating Cost (C) is represented by Equation (8).

$$\text{Operating Cost (C)} = A_1 P_S + A_2 Q_S \tag{8}$$

The operational cost minimization index is given by

$$XC_m = \frac{C_m}{C_0} \tag{9}$$

where C_0 indicates the initial operating cost before reconfiguration and C_m indicates the operating cost after reconfiguration in the mth system. The fuzzy satisfaction degree of the operating cost objective function is computed by exploiting the membership function, as represented by the fuzzy domain, which is expressed as follows:

$$\lambda C_m = \begin{cases} 1 & XC_m < XC_{\min} \\ \frac{XC_{\max} - XC_m}{XC_{\max} - XC_{\min}} & XC_{\min} < XC_m < XC_{\max} \\ 0 & XC_m > XC_{\max} \end{cases} \tag{10}$$

where, $XC_{\min}$ and $XC_{\max}$ are the lower and upper limits of XC_m index, correspondingly. To compute the $XC_{\min}$ and $XC_{\max}$, consider both the best and worst system configuration of the operating cost. C_m for the system's best configuration is the least value of the operating cost and for the system's worst configuration is anticipated to be equal to the operating cost of the initial configuration.

3.4. Reliability Optimization

The crucial principle for the optimal operation of any distribution network is the operational reliability. For the optimization process, the operational reliability is considered. The reliability is calibrated by computing failure cost. The interruption of the customer's activity is occurring by the service disruption to every customer. The total service interruption duration function is represented as Customer Interruption Cost (CIC), which boosts with time and the amount of the cost is piecewise conversely commensurate to the time. Here, Customer Interruption Cost is the measured cost averaged through time. Let the mth bus is being supplied power by the link, which is the nth element of the system. Let λ_n failures/year be the average failure rate of the nth element of the system and r_n minutes/year taken as "average failure duration" acknowledging records for considerable years. If L_m is the load of the mth bus, the "Cost of Service Interruption" for the consumer at the same bus is expressed by Equation (11)

$$IC_m^n = L_m \times \lambda_n \times r_n \times CIC(r_m) \tag{11}$$

In Equation (11), r_m is the entire service break period at the mth bus seeing all of the other breaks, which will be described later. The load is considered as the set of elements that are supplied to the mth bus. The indices generate a set $k(m)$. Using Equation (12) "total interruption cost" for a service break at the same bus can be computed.

$$IC_m = \sum_{n \in k(m)} IC_m^n = \sum_{n \in k(m)} L_m \times \lambda_n \times r_n \times CIC(r_m) \tag{12}$$

Rearranging Equation (12),

$$IC_m = L_m \left[\sum_{n \in k(m)} \lambda_n \times r_n \right] \times CIC(r_m) = L_m \left[\sum_{n \in k(m)} \lambda_n \right] \frac{\sum\limits_{n \in k(m)} \lambda_n \times r_n}{\sum\limits_{n \in k(m)} \lambda_n} \times CIC(r_m) \tag{13}$$

Defining $\lambda_m = \left[\sum\limits_{n \in k(m)} \lambda_n \right]$ and $r_m = \frac{\sum\limits_{n \in k(m)} \lambda_n \times r_n}{\sum\limits_{n \in k(m)} \lambda_n}$

λ_m represents "average interruption rate" and r_m represents "average interruption duration", those are foreseen by a consumer at the mth bus contemplating the failures of all components those committed to "service interruption" on the same bus. IC_m in Equation (13) is known as "value based reliability index", which is assessed by probabilistic study, probable financial loss in a year through the service break at the same bus. For a specific configuration "Total Interruption Cost (TIC)" can be expressed as in Equation (14).

$$TIC = \sum_{m=2}^{N} IC_m \tag{14}$$

where N is the total number of buses.

The total interruption cost index is given by

$$XT_m = \frac{TIC_m}{TIC_0} \tag{15}$$

where TIC_0 indicates the initial total interruption cost before reconfiguration and TIC_m indicates the total interruption cost after reconfiguration in the mth system. The fuzzy satisfaction degree for the total interruption costs is computed by exploiting the membership function as represented by the fuzzy domain, which is represented by Equation (16).

$$\lambda T_m = \begin{cases} 1 & XT_m < XT_{\min} \\ \frac{XT_{\max} - XT_m}{XT_{\max} - XT_{\min}} & XT_{\min} < XT_m < XT_{\max} \\ 0 & XT_m > XT_{\max} \end{cases} \tag{16}$$

where, $XT_{\min}$ and $XT_{\max}$ are the lower and upper limits of XT_m index, correspondingly. To compute the $XT_{\min}$ and $XT_{\max}$, consider both the best and worst system configuration of the operating cost. T_m is the minimum value of the entire interruption cost for the best system configuration and for the worst system configuration it is anticipated to be equal to the total interruption cost of the initial configuration. Finally, for reconfiguration in a deregulated environment, there are two objectives, namely, optimize "operational cost minimization and operational reliability maximization", as obtained by curtailing TIC of customer after merging two objectives

$$\lambda F_{Dm} = (\lambda C_m \times \lambda T_m)^{\frac{1}{3}} \tag{17}$$

Equation (17) is regarded as the "fitness function" to be maximized through the process of optimization so that the best well-matched configuration in the deregulated environment is obtained. The optimal network reconfiguration at the deregulated environment is obtained by the established "Fuzzy-Firefly algorithm", as used in [22] for the regulated environment.

3.5. DG and Capacitor Placement

The optimum location of DG and capacitor in UDN is decided by Equation (18) [26], which presents the mathematical expression of "Loss Sensitivity Factor" (LSF) of three phase UDN. LSF is arranged in descending order and the highest value is considered for placement of DG and capacitor.

$$
\begin{aligned}
LSF = \frac{dP_{Loss}}{d|I-\phi|} = {} & 2K_{br-n}|I_{br-a}|R_{br-\phi.a}\cos(\theta_{I-br-a} - \theta_{I-n-\phi}) \\
& + 2K_{br-n}|I_{br-b}|R_{br-\phi.b}\cos(\theta_{I-br-b} - \theta_{I-n-\phi}) \\
& + 2K_{br-n}|I_{br-c}|R_{br-\phi.c}\cos(\theta_{I-br-c} - \theta_{I-n-\phi})
\end{aligned}
\tag{18}
$$

where *K*, *I*, *br*, *n*, *φ*, and *R* are the voltage ratio, current, branch number, bus number, phase, and resistance.

The DG (Type-I i.e., delivers only active power) is placed at first to the most sensitive node and its size is determined by Bacteria foraging optimization algorithm (BFOA). The details of BFOA are available in [27]. The objective function in this case is given in Equation (19).

$$\text{Objective function (OF)} = \text{Minimize (Real power loss)} \tag{19}$$

Next, LSF is found once again. The capacitor is placed to the most sensitive node and its size is determined by Bacteria foraging optimization algorithm (BFOA). Here, DG is placed at first because the available LSF is related to resistance of the network. The proposed LSF-BFOA method for the placement of DG and capacitor is to be compared with the LSF-GA method. The details of Genetic algorithm (GA) are available in [28].

4. Outcomes and Discussion

In this section, the efficiency of the suggested algorithm is tested severely on diverse types of UDN. In MATLAB working platform the proposed method of LA is implemented on 13 node UDN at first to check its performance when compared to other existing techniques, and then finally implemented on 25 UDN. The system configuration is mentioned as follows:

SYSTEM CONFIGURATION:
Operating System (OS): Windows 8
RAM Capacity: 4 GB
Processor model: Intel Core i3-3210
Frequency of the system: 3.19 GHz
MATLAB 2013a

4.1. 13-Node UDN

The proposed method of LA is implemented on IEEE 13 node UDN having 20 equally distributed load. The network configuration and other parameters are available in [12]. Table 1 shows the outcomes obtained by the proposed method and that of by [12].

Table 1. Loss allocation (LA) obtained by proposed method and by method.

Branch No.	Method [12]				Proposed Method			
	Phase			Total Losses (kW)	Phase			Total Losses (kW)
	A	B	C		A	B	C	
632	17.912	4.787	18.38	41.079	17.51	4.521	17.45	39.481
633	0.401	0.195	0.218	0.814	0.385	0.21	0.234	0.829
634	2.542	1.408	1.531	5.481	2.539	1.502	1.529	5.57
645	--	2.389	0.360	2.749	--	2.44	0.39	2.83
656	--	0.270	0.269	0.539	--	0.26	0.271	0.531
671	13.624	−0.195	9.481	22.91	13.645	−0.186	10.338	23.797
680	0.502	0.251	0.085	0.838	0.502	0.342	0.185	1.029
684	0.304	--	--	0.304	0.306	--	--	0.306
611	0	--	--	--	0	--	--	0
652	0	--	0	--	0	--	0	0
692	0	0	0	0	0	0	0	0
675	3.144	0.397	0.606	4.147	3.542	0.413	0.533	4.488
Total Losses (kW)	38.429	9.502	30.93	78.861	38.429	9.502	30.93	78.861

The proposed method gives the loss allocation in more uniform way as compared to [12].

4.2. 25-Node UDN in Regulated Environment

A 25 node UDN is considered as a common test case having 4.16 kV, 30 MVA as base values. It consists of switches with three tie lines and the total load is 3.239 + j2.393 MVA. Network data are presented in [29]. Initial configuration of the network and final configuration after network reconfiguration are available in [22]. The detailed results for the base case and after network reconfiguration are also available in [22].

The voltage levels and LA to each consumer for base network and reconfigured network in a regulated environment are given in Table 2. The node number is for voltage level and branch number for loss allocation. This configuration has 25 nodes and 24 branches. The values in italics are for loss allocation.

Table 2. Voltage Levels and LA to each consumer for base network and reconfigured network.

Node No./*Branch No.*	Voltage Levels (p.u.)						Loss Allocated (kW)					
	Before Reconfiguration			After Reconfiguration			Before Reconfiguration			After Reconfiguration		
	Phase			Phase			Phase			Phase		
	A	B	C	A	B	C	A	B	C	A	B	C
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.02	0.03	0.009	0.02	0.03	0.006
2	0.9702	0.9711	0.9755	0.9805	0.9825	0.9880	0.05	0.04	0.039	0.05	0.04	0.021
3	0.9632	0.9644	0.9698	0.9798	0.9813	0.9825	0.1	0.1	0.06	0.1	0.09	0.04
4	0.9598	0.9613	0.9674	0.9786	0.9801	0.9805	0.12	0.12	0.07	0.1	0.1	0.07
5	0.9587	0.9603	0.9664	0.9601	0.9759	0.9730	0.21	0.40	0.26	0.2	0.38	0.11
6	0.9550	0.9559	0.9615	0.9797	0.9815	0.9871	0.87	1.51	1.6	0.55	0.43	0.38
7	0.9419	0.9428	0.9492	0.9775	0.9788	0.9838	0.21	0.60	0.92	0.2	0.31	0.21
8	0.9529	0.9538	0.9596	0.9790	0.9801	0.9850	2.48	2.87	1.78	0.41	0.52	1.08
9	0.9359	0.9367	0.9438	0.9755	0.9763	0.9788	6.8	4.47	4.12	2.12	1.13	1.1
10	0.9315	0.9319	0.9395	0.9699	0.9760	0.9755	7.68	5.38	5.8	2.21	1.32	1.01
11	0.9294	0.9296	0.9376	0.9619	0.9759	0.9738	9.76	12.30	9.52	2.37	2.14	1.27
12	0.9285	0.9287	0.9369	0.9587	0.9758	0.9730	7.88	7.44	6.962	2.28	3.33	2.1
13	0.9287	0.9287	0.9373	0.9581	0.9756	0.9728	2.41	2.79	2.81	0.68	1.1	0.52
14	0.9359	0.937	0.9434	0.9734	0.9758	0.9835	5.01	5.1	3.12	1.01	1.26	0.62
15	0.9338	0.9349	0.9414	0.9718	0.9755	0.9761	2.02	3.01	1.52	0.24	0.2	0.43
16	0.9408	0.9418	0.9483	0.9686	0.9757	0.9742	4.82	4.14	3.01	0.81	0.71	0.27
17	0.9347	0.936	0.9420	0.9685	0.9756	0.9830	0.14	0.2	0.08	0.11	0.12	0.02
18	0.9573	0.9586	0.9643	0.9676	0.9763	0.9738	0.38	0.82	0.3	0.31	0.61	0.11
19	0.9524	0.9544	0.9600	0.9623	0.9752	0.9736	0.30	0.38	0.19	0.2	0.17	0.12
20	0.9548	0.9563	0.9620	0.9631	0.9761	0.9737	0.31	0.51	0.29	0.2	0.5	0.08
21	0.9537	0.9549	0.9605	0.9634	0.9762	0.9735	0.61	1.02	1.1	0.24	0.12	0.04
22	0.9518	0.9525	0.9585	0.9628	0.9760	0.9733	0.14	0.26	0.08	0.12	0.14	0.07
23	0.9565	0.9584	0.9648	0.9697	0.9799	0.9797	0.18	0.34	0.09	0.13	0.12	0.03
24	0.9544	0.9565	0.9631	0.9696	0.9762	0.9736	0.42	0.61	0.24	0.19	0.16	0.05
25	0.952	0.9547	0.9612	0.9687	0.9760	0.9731	--	--	--	--	--	--

The DG and capacitor are integrated to the reconfigured UDN. The location DG and Capacitor are obtained by the LSF. Their sizes are determined by BFOA and Genetic Algorithm (GA) and the outcomes of both cases are presented in Table 3.

Table 3. Outcomes after Integration of distributed generations (DG) and Capacitor in reconfigured network by Bacteria foraging optimization algorithm (BFOA) and genetic algorithms (GA).

| Parameters | By GA | | | By BFOA | | |
| | Phase | | | Phase | | |
	A	B	C	A	B	C
Real Power Loss (kW)	4.99	5.21	3.45	4.89	4.96	3.20
Reactive Power Loss (kVAr)	6.35	5.68	3.72	6.01	5.45	3.42
Minimum Voltage (p.u.)	0.9798 (14)	0.9887 (14)	0.9869 (14)	0.9813 (13)	0.9901 (13)	0.9891 (13)
Switches Opened	6, 15, 17			-		
DG Location	8	8	8	7	7	7
DG Size (kW)	210	195	175	190	180	150
Capacitor Location	14	14	14	15	15	15
Capacitor Size (kVAr)	240	230	240	200	200	200

The DG and capacitor are integrated into the reconfigured network for three phase to reduce the losses and also the LA after the integration of DG and capacitor is carried out. The results before and after the integration of DG and capacitor in the reconfigured network are presented in Table 4.

Table 4. Outcomes after Integration of DG and Capacitor in reconfigured network.

Parameters	Before DG and Capacitor Placement			After DG and Capacitor Placement		
	Phase			Phase		
	A	B	C	A	B	C
Real Power Loss (kW)	14.95	15.03	9.75	4.89	4.96	3.20
Reactive Power Loss (kVAr)	17.30	15.39	9.54	6.01	5.45	3.42
Minimum Voltage (p.u.)	0.9581 (13)	0.9756 (13)	0.9728 (13)	0.9813 (13)	0.9901 (13)	0.9891 (13)
Switches Opened	6, 15, 17			-		
DG Location	-	-	-	7	7	7
DG Size (kW)	-	-	-	190	180	150
Capacitor Location	-	-	-	15	15	15
Capacitor Size (kVAr)	-	-	-	200	200	200
Energy Cost ($/kWh)	20,882.088			11,063.88		

The results of LA before and after integration of DG and capacitor in the reconfigured network, as well as the voltage levels of the system are presented in Table 5. The node number is for voltage level and branch number for loss allocation. This configuration has 25 nodes and 24 branches. The values in italics are for loss allocation.

Table 5. Voltage Levels and LA to consumer before and after integration of DG and capacitor in reconfigured network.

Node No./*Branch No.*	Voltage Levels (p.u.)						Loss allocated (kW)					
	Before Integration of DG and Capacitor			After Integration of DG and Capacitor			Before Integration of DG and Capacitor			After Integration of DG and Capacitor		
	Phase			Phase			Phase			Phase		
	A	B	C	A	B	C	A	B	C	A	B	C
1	1	1	1	1	1	1	0.02	0.03	0.006	0.02	0.02	0.005
2	0.9805	0.9825	0.9880	0.9994	0.9963	0.9946	0.05	0.04	0.021	0.03	0.04	0.015
3	0.9798	0.9813	0.9825	0.9993	0.9959	0.9931	0.10	0.09	0.04	0.08	0.07	0.04
4	0.9786	0.9801	0.9805	0.9989	0.9947	0.9919	0.10	0.10	0.07	0.05	0.06	0.02
5	0.9601	0.9759	0.9730	0.9853	0.9908	0.9898	0.20	0.38	0.11	0.11	0.17	0.03
6	0.9797	0.9815	0.9871	0.9992	0.9962	0.9945	0.55	0.43	0.38	0.19	0.22	0.31
7	0.9775	0.9788	0.9838	0.9989	0.9939	0.9930	0.20	0.31	0.21	0.06	0.18	0.1
8	0.9790	0.9801	0.9850	0.9990	0.9948	0.9943	0.41	0.52	1.08	0.32	0.25	0.3
9	0.9755	0.9763	0.9788	0.9988	0.9933	0.9915	2.12	1.13	1.10	0.99	0.42	0.34
10	0.9699	0.9760	0.9755	0.9972	0.9923	0.9914	2.21	1.32	1.01	0.8	0.41	0.33
11	0.9619	0.9759	0.9738	0.9883	0.9910	0.9912	2.37	2.14	1.27	0.96	0.81	0.42
12	0.9587	0.9758	0.9730	0.9825	0.9905	0.9896	2.28	3.33	2.10	0.7	0.44	0.53
13	0.9581	0.9756	0.9728	0.9813	0.9901	0.9891	0.68	1.10	0.52	0.18	0.36	0.13
14	0.9734	0.9758	0.9835	0.9984	0.9923	0.9929	1.01	1.26	0.62	0.03	0.45	0.17
15	0.9718	0.9755	0.9761	0.9980	0.9917	0.9913	0.24	0.20	0.43	0.01	0.13	0.14
16	0.9686	0.9757	0.9742	0.9953	0.9921	0.9899	0.81	0.71	0.27	0.08	0.06	0.09
17	0.9685	0.9756	0.9830	0.9949	0.9918	0.9909	0.11	0.12	0.02	0.01	0.06	0.01
18	0.9676	0.9763	0.9738	0.9940	0.9925	0.9917	0.31	0.61	0.11	0.06	0.19	0.02
19	0.9623	0.9752	0.9736	0.9891	0.9903	0.9910	0.2	0.17	0.12	0.018	0.09	0.03
20	0.9631	0.9761	0.9737	0.9907	0.9921	0.9915	0.2	0.50	0.08	0.012	0.2	0.02
21	0.9634	0.9762	0.9735	0.9915	0.9924	0.9914	0.24	0.12	0.04	0.06	0.07	0.05
22	0.9628	0.9760	0.9733	0.9901	0.9919	0.9907	0.12	0.14	0.07	0.02	0.08	0.01
23	0.9697	0.9799	0.9797	0.9969	0.9947	0.9918	0.13	0.12	0.03	0.03	0.03	0.05
24	0.9696	0.9762	0.9736	0.9966	0.9932	0.9908	0.19	0.16	0.05	0.07	0.08	0.04
25	0.9687	0.9760	0.9731	0.9956	0.9927	0.9898	--	--	--	--	--	--

Figures 1a, 2a and 3a show the representation of voltage levels of the Phases A–C, respectively, before and after the integration of DG and capacitor in the reconfigured network. Figures 1b, 2b and 3b show the LA of the Phases A–C, respectively, before and after the integration of DG and capacitor in the reconfigured network.
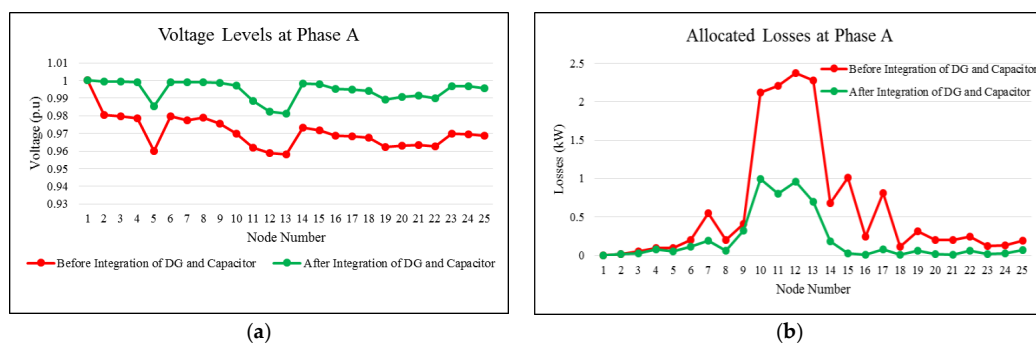
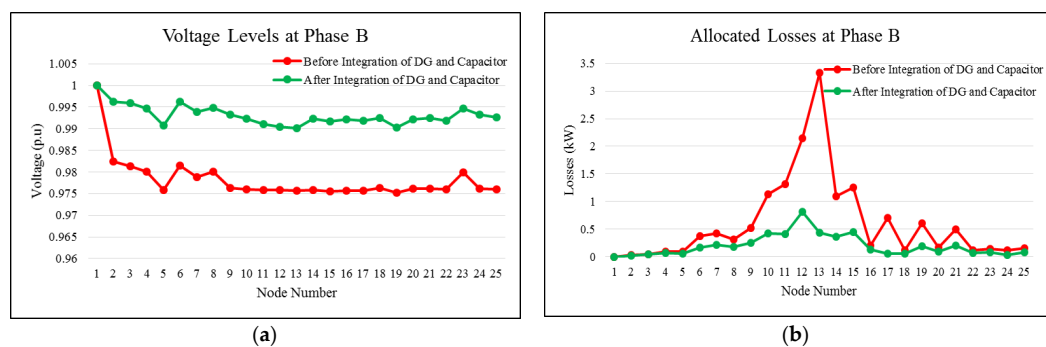**Figure 1.** (**a**) Voltage Level at Phase A. (**b**) LA in Phase A.

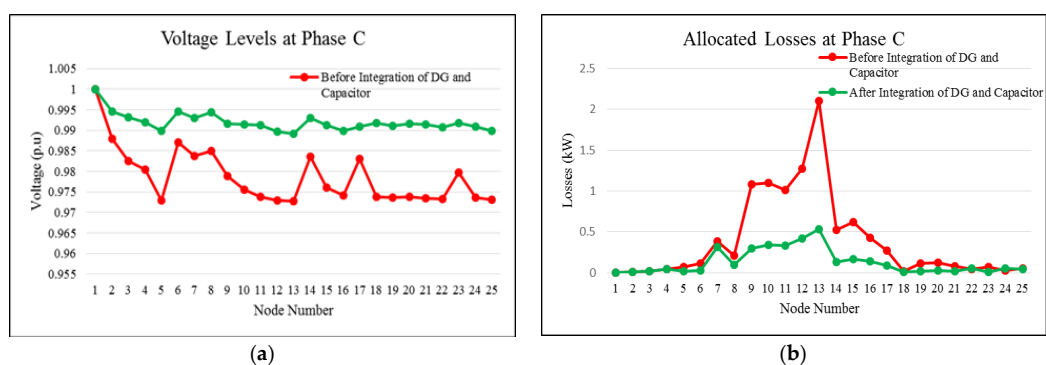**Figure 2.** (**a**) Voltage Level at Phase B. (**b**) LA in Phase B.

Figure 3. (**a**) Voltage Level at Phase C. (**b**) LA in Phase C.

4.3. 25-Node UDN in Deregulated Environment

In a deregulated environment, data of equipment failure is given in Table 6 [15], and "the customer interruption cost" in $ per minute per kW are given in Table 7 [15] and K_1 = 5$/kW and K_2 = 2$/kVAr [15], respectively and the customers considered are of commercial type load.

**Table 6.** Equipment Failure Data.

Equipment	Failure Rate (Failure/Year)	Failure Duration (Min/Failure)
Cable	3.0×10^{-5}/m	150
Elbow	6.0×10^{-4}	110
Fuse	3.7×10^{-3}	50
Fault Interrupter	5.0×10^{-3}	100
Overhead line	6.0×10^{-5}/m	100
Splice	6.0×10^{-4}	200
Switch	4.0×10^{-3}	60
Transformer	2.0×10^{-3}	160

Table 7. Customer interruption rates in C$/min/kW.

Duration	Commercial Load
1	0.492
20	0.259
60	0.253
240	0.241
480	0.284

The 25 node UDN is reconfigured in the deregulated environment and the final configuration is shown in Figure 4. The simulation results of this network before and after network reconfiguration is shown in Table 8.
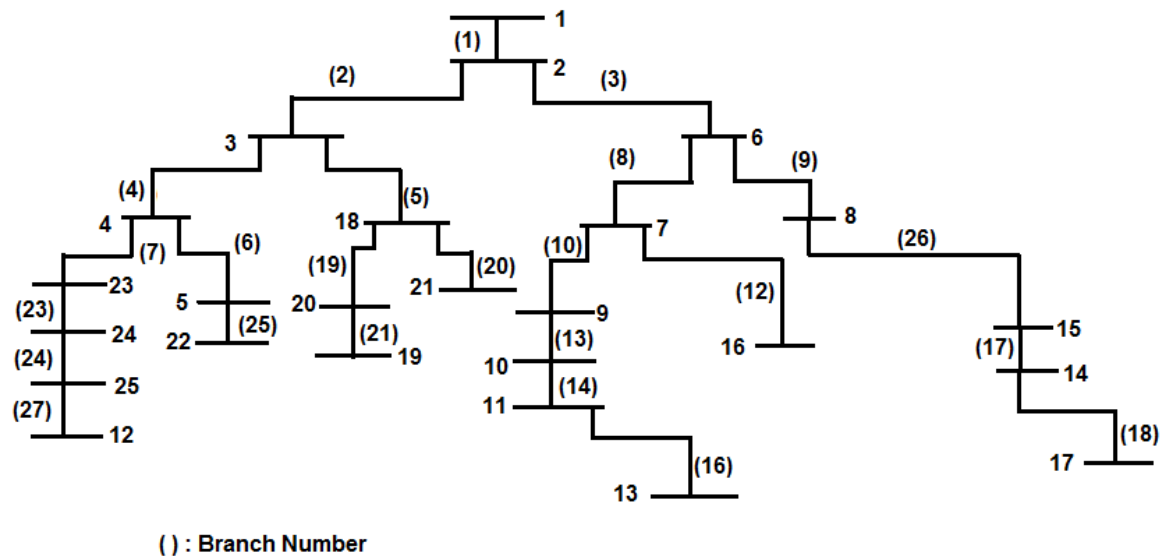
Figure 4. Reconfigured Network.

Table 8. Results obtained in deregulated environment.

Parameters	Before Reconfiguration			After Reconfiguration		
	Phase			Phase		
	A	B	C	A	B	C
Real Power Loss (kW)	52.92	54.44	43.97	29.34	32.025	25.87
Reactive Power Loss (kVAr)	60.43	52.32	55.87	50.21	42.78	45.29
Operating Cost (C$)		8355.080			4816.331	
Total Interruption Cost (C$)		102.90			46.29	
Switches Opened		25, 26, 27			11, 15, 22	
Energy Cost ($/kWh)		79,539.048			45,850.716	

The voltage levels and LA in the deregulated environment before and after network reconfiguration are shown in Table 9. The node number is for voltage level and branch number for loss allocation. This configuration has 25 nodes and 24 branches. The values in italics are for loss allocation.

Figures 5a, 6a and 7a show the representation of voltage levels of base and reconfigured networks for the Phases A–C, respectively. Figures 5b, 6b and 7b show the loss allocated base and reconfigured networks for the Phases A–C, respectively. The voltage level has been improved after network reconfiguration. Since the losses are reduced after network reconfiguration, the amount of allocated loss is also reduced.

**Table 9.** Voltage Levels and LA to consumer before and after reconfiguration in deregulated environment.

Node No./*Branch No.*	Voltage Levels (p.u.)						Loss Allocated (kW)					
	Base Network			Reconfigured Network			Base Network			Reconfigured Network		
	Phase			Phase			Phase			Phase		
	A	B	C	A	B	C	A	B	C	A	B	C
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.02	0.03	0.01	0.02	0.03	0.008
2	0.9702	0.9711	0.9755	0.9824	0.9893	0.9871	0.05	0.04	0.04	0.04	0.03	0.03
3	0.9632	0.9644	0.9698	0.9754	0.9880	0.9814	0.10	0.10	0.06	0.10	0.06	0.06
4	0.9598	0.9613	0.9674	0.9720	0.9849	0.9790	0.12	0.12	0.07	0.10	0.06	0.06
5	0.9587	0.9603	0.9664	0.9717	0.9844	0.9771	0.21	0.40	0.26	0.12	0.15	0.22
6	0.9550	0.9559	0.9615	0.9672	0.9741	0.9731	0.87	1.51	1.6	0.36	1.02	0.94
7	0.9419	0.9428	0.9492	0.9541	0.9659	0.9607	0.21	0.60	0.92	0.12	0.5	0.81
8	0.9529	0.9538	0.9596	0.9661	0.9722	0.9701	2.48	2.87	1.78	1.91	1.81	1.18
9	0.9359	0.9367	0.9438	0.9487	0.9618	0.9563	6.80	4.47	4.12	3.99	3.25	3.11
10	0.9315	0.9319	0.9395	0.9447	0.9580	0.9530	7.68	5.38	5.8	3.98	3.87	3.20
11	0.9294	0.9296	0.9376	0.9415	0.9534	0.9520	9.76	12.30	9.52	4.74	7.12	5.14
12	0.9285	0.9287	0.9369	0.9515	0.9612	0.9688	7.88	7.44	6.96	3.45	3.11	3.14
13	0.9287	0.9287	0.9373	0.9399	0.9516	0.9514	2.41	2.79	2.81	1.53	1.25	1.89
14	0.9359	0.9370	0.9434	0.9621	0.9629	0.9628	5.01	5.10	3.12	3.45	3.06	1.85
15	0.9338	0.9349	0.9414	0.9640	0.9661	0.9661	2.02	3.01	1.52	1.19	1.54	0.88
16	0.9408	0.9418	0.9483	0.9500	0.9655	0.9565	4.82	4.14	3.01	2.92	2.21	1.612
17	0.9347	0.9360	0.9420	0.9598	0.9624	0.9614	0.14	0.20	0.08	0.11	0.11	0.07
18	0.9573	0.9586	0.9643	0.9681	0.9851	0.9771	0.38	0.82	0.3	0.24	0.63	0.21
19	0.9524	0.9544	0.9600	0.9633	0.9784	0.9714	0.30	0.38	0.19	0.16	0.22	0.16
20	0.9548	0.9563	0.9620	0.9645	0.9824	0.9754	0.31	0.51	0.29	0.13	0.21	0.21
21	0.9537	0.9549	0.9605	0.9647	0.9830	0.9759	0.61	1.02	1.1	0.25	0.87	0.81
22	0.9518	0.9525	0.9585	0.9668	0.9778	0.9681	0.14	0.26	0.08	0.09	0.21	0.07
23	0.9565	0.9584	0.9648	0.9667	0.9831	0.9759	0.18	0.34	0.09	0.10	0.30	0.06
24	0.9544	0.9565	0.9631	0.9655	0.9803	0.9724	0.42	0.61	0.24	0.24	0.40	0.15
25	0.952	0.9547	0.9612	0.9611	0.9753	0.9698	--	--	--	--	--	--
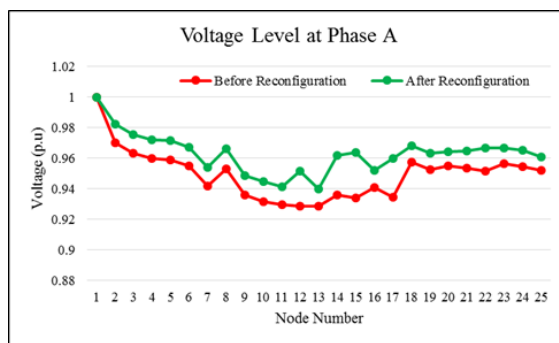
(**a**)
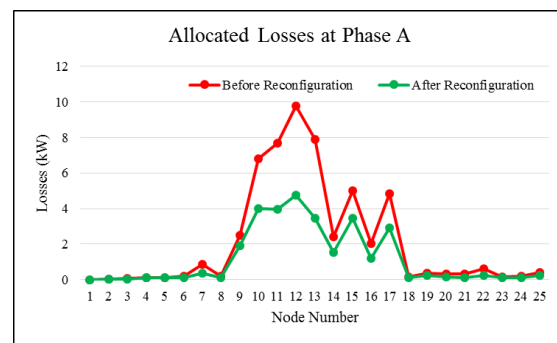
(**b**)

Figure 5. (**a**) Voltage Level at Phase A. (**b**) LA in Phase A.
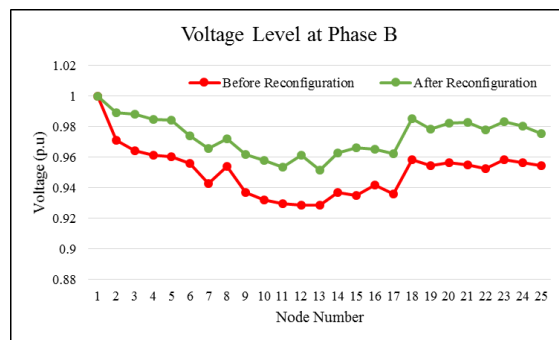
(**a**)
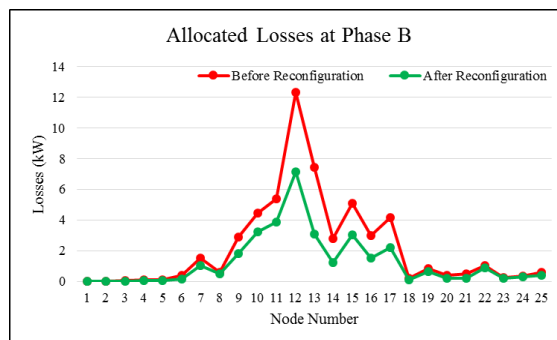
(**b**)

Figure 6. (**a**) Voltage Level at Phase B. (**b**) LA in Phase B.

(**a**) (**b**)

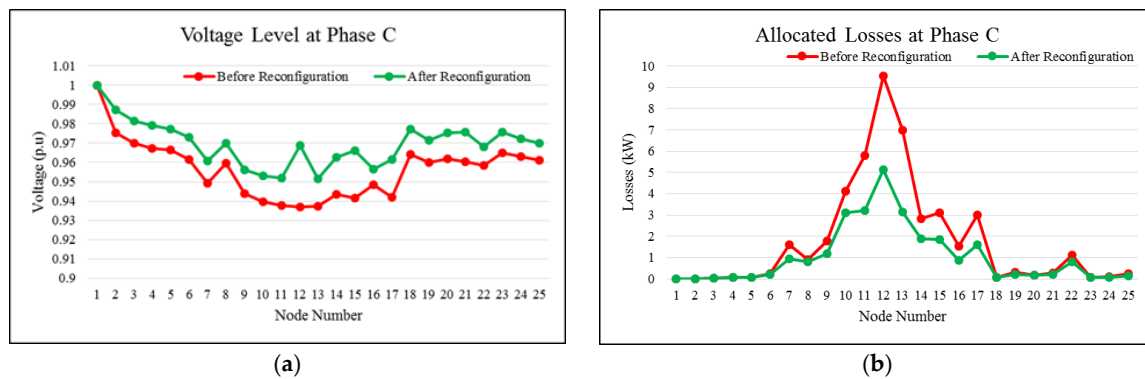**Figure 7.** (**a**) Voltage Level at Phase C. (**b**) LA in Phase C.

The DG and capacitor are being integrated into the reconfigured network in a deregulated environment to further reduce the losses. The results before and after the integration of DG and capacitor in the reconfigured network are shown in Table 10.

Table 10. Results after Integration of DG and Capacitor in Figure 4.

| Parameters	Before DG and Capacitor Placement			After DG and Capacitor Placement		
	Phase			Phase		
	A	B	C	A	B	C
Real Power Loss (kW)	29.34	32.025	25.87	19.6	20.99	16.42
Reactive Power Loss (kVAr)	50.21	42.78	45.29	30.24	23.41	24.87
Minimum Voltage (p.u.)	0.9399	0.9516	0.9514	0.9449 (13)	0.9632 (13)	0.9612 (13)
Switches Opened	11, 15, 22			-		
DG Location	-	-	-	12	12	12
DG Size (kW)	-	-	-	185	185	185
Capacitor Location	-	-	-	8	8	8
Capacitor Size (kVAr)	-	-	-	190	190	190
Energy Cost ($/kWh)	45,850.716			29,964.456		

The voltage levels and LA in the deregulated environment before and after integration of DG and capacitor are shown in Table 11. The node number is for voltage level and branch number for loss allocation. This configuration has 25 nodes and 24 branches. The values in italics are for loss allocation.

Figures 8a, 9a and 10a show the representation of voltage levels of the Phases A–C, respectively, before and after integration of DG and capacitor in the reconfigured network. Figures 8b, 9b and 10b show the LA of the Phases A–C, respectively, before and after integration of DG and capacitor in the reconfigured network.

From these results, the losses are allocated before and after network reconfiguration in regulated and deregulated environments, as well as we have analyzed LA after the integration of DG and capacitor in the reconfigured network in both of the environments. Nowadays, in most of the existing research, the main focus was on balanced DNs but in the proposed method we have concentrated on unbalanced DN. In the already existing works, the focus is either on network reconfiguration, DG placement, or capacitor placement. Here, in our work, we are combining the advantage of network reconfiguration, DG, and capacitor placement, and we also have shown the impact of these in LA in both the regulated and deregulated environment.

Table 11. LA to consumer before and after Integration of DG and Capacitor in reconfigured network in deregulated environment.

| Node No./*Branch No.*	Voltage Levels (p.u.)						Loss Allocated (kW)					
	Before Integration of DG and Capacitor			After Integration of DG and Capacitor			Before Integration of DG and Capacitor			After Integration of DG and Capacitor		
	Phase			Phase			Phase			Phase		
	A	B	C	A	B	C	A	B	C	A	B	C
1	1	1	1	1	1	1	0.02	0.03	0.008	0.02	0.02	0.003
2	0.9824	0.9893	0.9871	0.9899	0.9912	0.9915	0.04	0.03	0.03	0.03	0.02	0.03
3	0.9754	0.9880	0.9814	0.9843	0.9982	0.9822	0.1	0.06	0.06	0.08	0.05	0.05
4	0.9720	0.9849	0.9790	0.9785	0.9912	0.9799	0.1	0.06	0.06	0.075	0.04	0.04
5	0.9717	0.9844	0.9771	0.9773	0.9891	0.9782	0.12	0.15	0.22	0.072	0.11	0.12
6	0.9672	0.9741	0.9731	0.9777	0.9789	0.9877	0.36	1.02	0.94	0.21	0.36	0.71
7	0.9541	0.9659	0.9607	0.9631	0.9697	0.9753	0.12	0.5	0.81	0.1	0.12	0.38
8	0.9661	0.9722	0.9701	0.9745	0.9779	0.9817	1.91	1.81	1.18	1.12	1.38	0.51
9	0.9487	0.9618	0.9563	0.9577	0.9676	0.9687	3.99	3.25	3.11	2.48	2.09	2.79
10	0.9447	0.9580	0.9530	0.9497	0.9656	0.9644	3.98	3.87	3.2	2.39	2.44	2.14
11	0.9415	0.9534	0.9520	0.9481	0.9641	0.9624	4.74	7.12	5.14	2.85	4.87	3.20
12	0.9515	0.9612	0.9688	0.9559	0.9698	0.9690	3.45	3.11	3.14	3.01	2.06	2.47
13	0.9399	0.9516	0.9514	0.9449	0.9632	0.9612	1.53	1.25	1.89	0.47	0.89	0.9
14	0.9621	0.9629	0.9628	0.9653	0.9680	0.9648	3.45	3.06	1.85	2.85	2.07	0.81
15	0.9640	0.9661	0.9661	0.9705	0.9738	0.9721	1.19	1.54	0.88	0.7	1.02	0.49
16	0.9519	0.9655	0.9565	0.9595	0.9689	0.9699	2.92	2.215	1.612	2.193	1.69	0.84
17	0.9598	0.9624	0.9614	0.9611	0.9665	0.9640	0.11	0.11	0.07	0.1	0.08	0.06
18	0.9681	0.9851	0.9771	0.9737	0.9870	0.9785	0.24	0.63	0.21	0.17	0.41	0.15
19	0.9633	0.9784	0.9714	0.9701	0.9819	0.9742	0.16	0.22	0.16	0.09	0.16	0.09
20	0.9645	0.9824	0.9754	0.9731	0.9839	0.9759	0.13	0.21	0.21	0.08	0.14	0.11
21	0.9647	0.9830	0.9759	0.9711	0.9841	0.9764	0.25	0.87	0.81	0.14	0.39	0.32
22	0.9668	0.9778	0.9681	0.9724	0.9811	0.9699	0.09	0.21	0.07	0.08	0.18	0.05
23	0.9667	0.9831	0.9759	0.9725	0.9869	0.9769	0.1	0.3	0.06	0.08	0.21	0.04
24	0.9655	0.9803	0.9724	0.9689	0.9842	0.9738	0.24	0.4	0.15	0.21	0.19	0.11
25	0.9611	0.9753	0.9698	0.9642	0.9799	0.9724	--	--	--	--	--	--
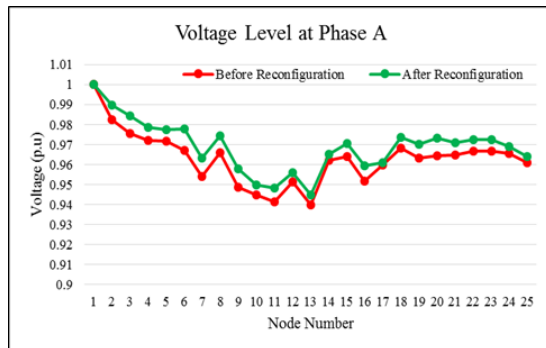
(a)
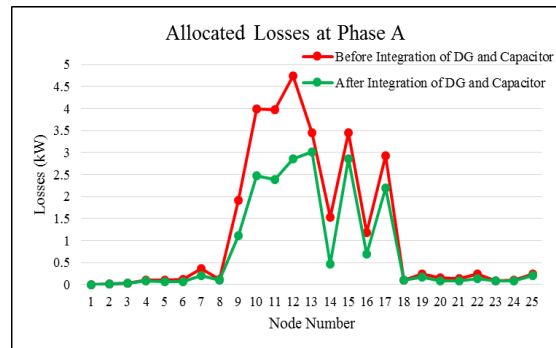
(b)

Figure 8. (**a**) Voltage Level at Phase A. (**b**) LA in Phase A.
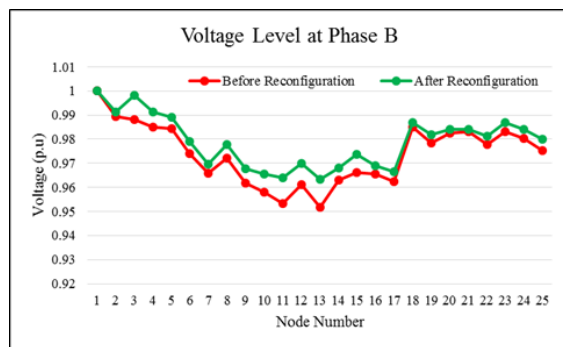
(a)
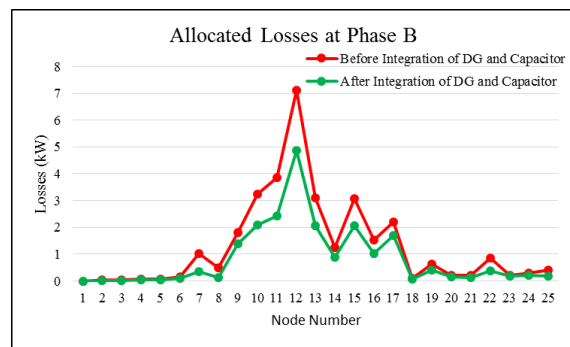
(b)

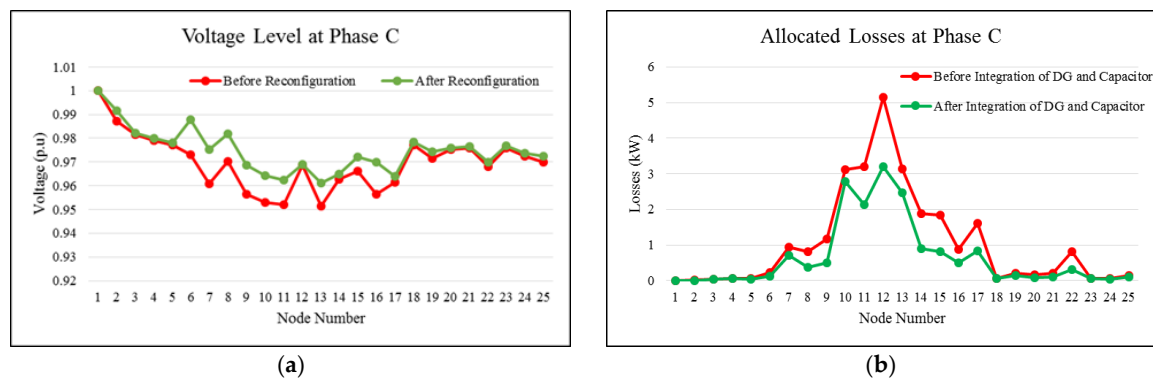**Figure 9.** (**a**) Voltage Level at Phase B. (**b**) LA in Phase B.

Figure 10. (**a**) Voltage Level at Phase C. (**b**) LA in Phase C.

5. Conclusions

This paper presents loss allocation of UDN in regulated and deregulated environments before and after minimizing the loss. Reconfiguration can reduce the loss of the system. Optimal placement of DG and capacitor in the reconfigured network further reduces the loss of the system. The loss allocations of base and reconfigured network in both environments are carried out using the Firefly algorithm. The reconfiguration of UDN in a regulated environment is available in [22]. The method [22] is extended to get the reconfiguration in the deregulated environment. The DG and capacitor are placed optimally in the reconfigured network in both of the environments using LSF and BFOA. The LA of this UDN is further carried out in both of the environments. The suggested method is implemented on MATLAB platform and is tested on a 25 node UDN. The simulation results that are obtained by the proposed method provide a clear representation of LA in UDN before and after network reconfiguration. The LA before and after integration of DG and capacitor in the reconfigured network in each environment has also been carried out.

Author Contributions: The problem formulation had been carried out by both the authors. The data collection, code development and implementation of code; and writing of the paper had been carried out by the First author.

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