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Distribution Network Reconfiguration for Voltage Profile Enhancement and Power Loss Reduction Under Hourly Energy Consumption Using Quantum Approximate Optimization Algorithm

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ABSTRACT

This paper presents a dynamic reconfiguration of a 33-bus power distribution network using the Quantum Approximate Optimization Algorithm (QAOA). The primary objectives are voltage profile improvement and power loss minimization, critical factors for enhancing the overall performance and efficiency of distribution networks. The proposed method adapts to hourly load variations, utilizing real consumer load profiles to account for dynamic changes throughout the day. By incorporating QAOA into the reconfiguration process, the system explores optimal configurations that reduce losses and improve voltage stability under varying operational conditions. The study's findings demonstrate the effectiveness of this approach in dynamically optimizing power distribution networks, contributing to reliable and efficient energy systems.

Kuantum Yaklaşık Optimizasyon Algoritması Kullanılarak Saatlik Enerji Tüketimi Altında Güç Kaybının Azaltılması ve Gerilim Profilinin İyileştirilmesi için Dağıtım Şebekesinin Yeniden Yapılandırılması

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ÖZ

Bu çalışmada, Kuantum Yaklaşık Optimizasyon Algoritması (QAOA) kullanarak 33 baralı bir elektrik dağıtım şebekesinin dinamik olarak yeniden yapılandırılması gerçekleştirilmiştir. Çalışmanın temel amacı, dağıtım şebekelerinin genel performansını ve verimliliğini artırmak için kritik faktörler olan güç kaybı minimizasyonu ve voltaj profilinin iyileştirilmesidir. Önerilen yöntem, gün boyunca dinamik değişiklikleri hesaba katarak ve gerçek tüketici yük profillerini kullanarak saatlik yük değişimlerine uyum sağlar. Sistem, OAQA'yı yeniden yapılandırma sürecine dahil ederek, değişen operasyonel koşullar altında kayıpları azaltan ve voltaj kararlılığını artıran optimum yapılandırmaları araştırmıştır. Çalışmanın bulguları, bu yaklaşımın elektrik dağıtım şebekelerini dinamik olarak optimize etmedeki etkinliğini göstermekte ve güvenilir ve verimli enerji sistemlerine katkıda bulunmaktadır.

1. INTRODUCTION

The power distribution network (PDN) is designed to minimize line losses while maintaining bus voltage levels within specified limits during the transmission of electrical energy. In the face of load fluctuations or grid malfunctions, it is imperative that active losses and bus voltage levels remain within acceptable parameters. This can be achieved through the strategic modification of switching positions within the PDN. The process of adapting the switching arrangements in response to changes in the topology of the power system is referred to as reconfiguration [1]. In this context, it is essential to protect the radial structure of the grid while ensuring uninterrupted power supply to consumers connected to the buses. Two types of switches are employed in distribution networks: sectionalizing switches (SSs) and tie-switches (TSs). By optimizing the switching status, the reconfiguration process aims to effectively reduce losses and enhance voltage stability, thereby facilitating reliable operation of the system. The approaches documented in the literature for addressing the distribution network reconfiguration (DNR) problem can be categorized into two main types: deterministic methods and meta-heuristic techniques [1]. Deterministic methods typically employ complex linear and nonlinear programming techniques during the reconfiguration process. However, these approaches often struggle to achieve a global optimal solution when confronted with nonconvex or highly nonlinear problems, which can be challenging to differentiate. As a result, they frequently become trapped in local optima, limiting their effectiveness in finding the best possible configuration [2]. Thus, heuristic and metaheuristic techniques have been introduced as viable alternatives to conventional methods, offering greater flexibility and a higher likelihood of achieving global optimal solutions [3]. In the context of power distribution networks, all studies conducted thus far on the reconfiguration technique for system improvement have been summarized in [4,5]. Recently, a variety of metaheuristic algorithms were applied to the reconfiguration problem in [1], and multiple case studies were considered to identify the algorithm that provides the optimal solution to the problem. Furthermore, the reconfiguration problem has been tackled in [6] by taking into account the unbalanced nature of the PDN [7]. In most of the studies, different optimization algorithms have been evaluated considering peak load conditions and applied to 69-bus and 33-bus PDN.

In this study, the reconfiguration of the 33-bus electrical distribution system was investigated using the Quantum Approximate Optimization Algorithm (QAOA). QAOA was chosen due to its ability to efficiently handle combinatorial optimization problems, which are inherent in DNR. Traditional optimization methods often struggle with the increasing complexity and size of modern distribution networks, leading to computational inefficiencies. QAOA leverages quantum mechanics to explore solution spaces more effectively, offering potential advantages in terms of convergence speed and solution quality. Two different scenarios were considered for the distribution grid. In the first scenario, optimal switching positions were determined based on the peak load values derived from the 33-bus test system data. The outcomes were compared with existing literature, thereby assessing the suitability of the QAOA approach for the reconfiguration of PDN. In the second scenario, in contrast to other studies, real-time consumer load profiles were utilized, assuming that the buses experienced variable loads. The system was reconfigured on an hourly basis, taking into account the bus load values. Additionally, the QAOA algorithm was executed 100 times, and the results were evaluated statistically. Key metrics such as the algorithm's elapsed time, losses, and improvements in bus voltage were assessed by identifying the best and worst switching positions. Furthermore, the appropriate inertia weight constant value for the QAOA used in the scenarios was statistically determined for the reconfiguration of the lines.

The remainder of the paper is structured as follows: Section 2 formulates the problem of reconfiguration in PDNs, while Section 3 introduces the QAOA employed in the study. Section 4 presents case studies and discusses the results obtained, finally concluding with a summary in the final section.

2. PROBLEM FORMULATION

In the distribution systems are expected to ensure the minimum level of active power losses and bus voltage within the nominal limits. For this purpose, the objective function of the QAOA is designed and presented in the study.

2.1. Minimization of the Active Power Losses

The active power losses in the PDN with N buses are defined by the Equation (1) [8].

$$P_{loss(i,i+1)} = \frac{P_i^2+Q_i^2}{V_i^2} . r_{(i,i+1)} \tag{1}$$

In Equation 1 P_i and Q_i terms are the active and reactive power values in the i^{th} bus, respectively. The $r_{i,i+1}$ term is the line resistance between the branches of i and i+1. V_i refers to bus voltage at the i^{th} node. The total power loss in the distribution grid with N buses and m branches is defined by the Equation 2 [9].

$$P_{losses} = \sum_{i=1}^{m} k_{(i,i+1)} . \left(\frac{P_i^2+Q_i^2}{V_i^2}\right) . r_{(i,i+1)} \tag{2}$$

A radiality criteria of the PDN is the criterion of m=N-1. This criterion always has to be met. The term $k_{i,i+1}$ indicates whether the branch of the distribution line is in energized or not. If the branch is in energized then k=1, and in case the switch is off then k=0.

2.2. Bus Voltage Limitation

In PDN the bus voltage levels must be within certain limits as shown in Equation 3 [10].

$$V_{min}^i \leq V_{bus}^i \leq V_{max}^i \tag{3}$$

The limit values for the bus voltage are $0.9. V_{bus}^i \leq V_{bus}^i \leq 1.1. V_{bus}^i$ pu. The permissible voltage range for the supply nodes is assumed to be $0.95. V_{feeder}^i \leq V_{feeder}^i \leq 1.05. V_{feeder}^i$ pu.

2.3. Optimization Constraint

The following constraints should be taken into consideration when determining the optimal switching status criteria in the distribution grid.

2.3.1. Branches Current Limitation

The maximum value of the current must not exceed the current carrying capacity of the line as demonstrated in Equation 4 [10].

$$I_{branches}^i \leq I_{max}^i \tag{4}$$

2.3.2. Preserving the Radial Topological Structure of the Distribution Grid and Radiality Check

PDN are generally designed in a radial structure [11]. The method for ensuring radiality in PDNs is extensively detailed in [12]. Additionally, [12] also discusses how PDNs can transition into a non-radial structure after the integration of distributed generators and presents proposed solutions to address this issue. It is aimed to preserve the radial structure also after changing the position of the switches in the system. Equation 5 refers to the number of switches that must be turned on to provide a radial structure [12].

$$\Lambda = B - N + S \tag{5}$$

where B, N and S are number of branches, bus and feeder, respectively. Actually, this criterion is strongly connected with m=N-1. The system must also meet the following conditions to have a radial structure.

- ✓ All loads in the system must be fed by the same feeder.
- ✓ There must be no loop (acyclic) structure in the line.

In this case, the number of SSs in the PDN is determined using the Equation 6.

$$N_{SSs} = N_{Bus} - 1 \tag{6}$$

The required conditions for preserving the line radiality at the end of the reconfiguration are defined by Equations (5) - (6). Bus incidence matrix [11] must be created to check radiality. The matrix is created using Equation 7.

$$\hat{A} = \begin{cases} -1 \; or \; 1 & Radial \\ 0 & Not \; Radial \end{cases} \tag{7}$$

If $|\det(A)| = 1$ then the system is radial, and all loads connected to the buses are powered by a single source.

3. QUANTUM APPROXIMATE OPTIMIZATION ALGORTIHM

Quantum Approximate Optimization Algorithm is a hybrid quantum-classical algorithm designed to solve combinatorial optimization problems [13]. This algorithm generates solutions over a parametric quantum circuit using both quantum and classical resources. QAOA alternates between phase separator operators (which encode the cost function) and mixing operators (which explore the solution space). These operations are repeated for a given number of layers, and the parameters are tuned by classical optimization methods to achieve the smallest value of the objective function. Mathematically, QAOA uses the problem Hamiltonian H_C and the mixture Hamiltonian H_M to be minimized. For certain parameters $\vec{\gamma}$ and $\vec{\beta}$, the quantum state evolves as follows:

$$|\psi(\vec{\gamma},\vec{\beta})\rangle = U_M(\beta_p)U_C(\gamma_p)..U_M(\beta_1)U_c(\gamma_1)|s\rangle \tag{8}$$

where $U_C(\gamma) = e^{-i\gamma H_C}$ and $U_M(\beta) = e^{-i\beta H_M}$ and $|s\rangle$ s is the initial quantum state. The parameters $\vec{\gamma}$ and $\vec{\beta}$ are optimized by classical methods to obtain convergent solutions to the reconfiguration problem of PDNs. This method aims to offer a quantum advantage, especially in large-scale optimization problems, but its full potential will be better understood with the development of quantum hardware.

4. CASE STUDY&RESULTS

A dynamic study to minimize the active power loss using 24-hour variable load profiles is performed by applying it to a 33-bus test system. The load flow analysis of the power system has been performed on an hourly basis using real-time consumer load profiles. Furthermore, the iteration number of the QAOA is set to 100 and the results are statistically evaluated. Algorithm's loop-elapsed-time, power losses and the voltage improvement in PDN are evaluated by determining the best and worst switching positions.

Figure 1 shows the 33-bus power distribution test system. This system includes 1 feeder, 5 TSs (dashed lines), and 32 SSs. The objective function of the reconfiguration operation is to improve the voltage profile and to reduce the active power losses in the PDN. In the scenario, the system was optimized hourly under dynamic load by preserving the radiality of the distribution system.

Consumer load profiles of the distribution company for the April 2023 period are used to define dynamic loads. Changes in switching positions are examined for 24 hours. The data based on the weekly average load values of residential and commercial consumers are used. The power factor is assumed to be 0.90 and 0.71 for residential and commercial consumers, respectively, with 80% of the total load coming from residential consumers and 20% from commercial consumers.

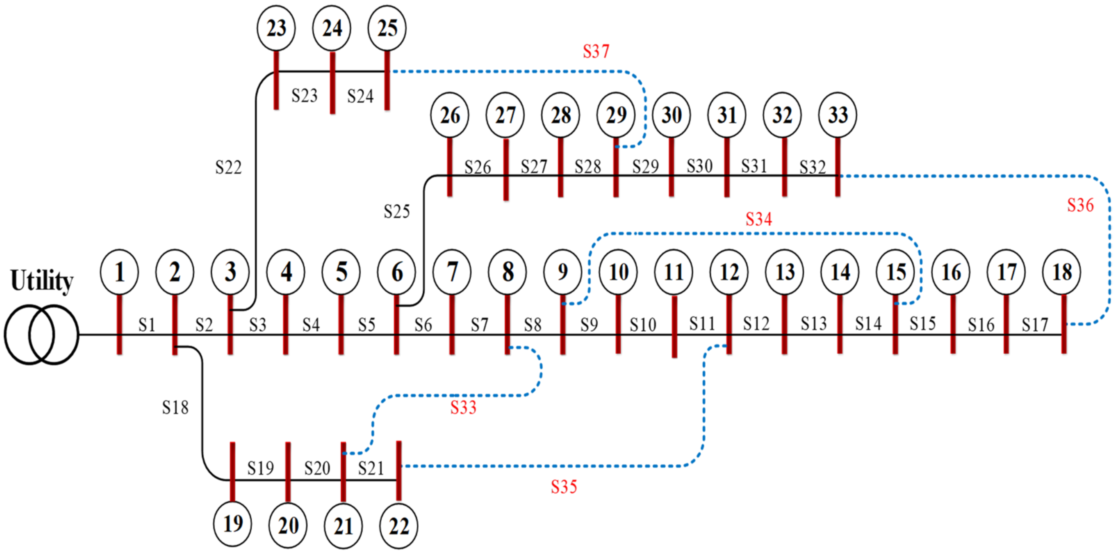

Figure 1. 33-bus test system [1]

4.1. Reconfiguration of 33-Bus Power Distribution Network under Dynamic Load

The configuration of the system remains unchanged even when the loads connected to the bus decrease or increase linearly in relation to the peak load. In order to create the dynamic structure, the number of consumers assigned to each bus is randomly determined. The load variations of the 33-bus system are defined on an hourly basis, and the consumers' load data used to determine the dynamic structure can be seen in Figure 2 and Figure 3.

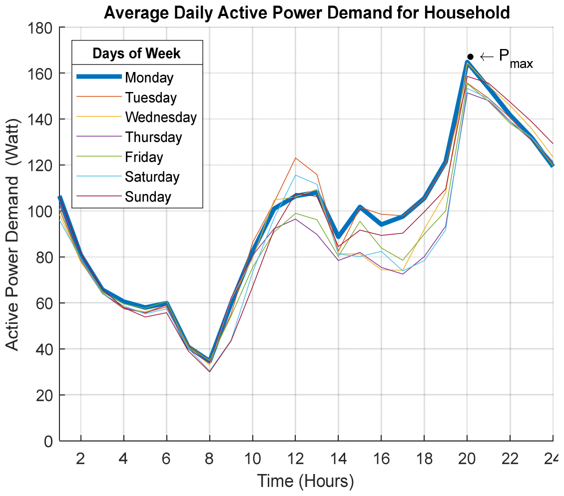

Figure. 2. Weekly load profile of real residential consumers provided by the distribution company for the month of April

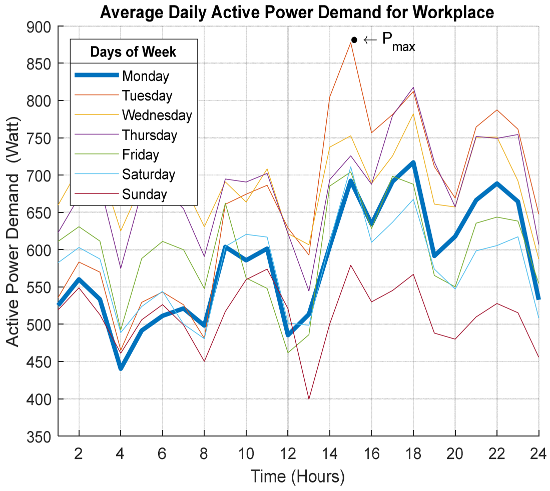

Figure. 3. Weekly load profile of real commercial consumers provided by the distribution company for the month of April

The numbers of residential and commercial consumers connected to the buses are randomly assigned, and their variations for different periods are graphically displayed in Figure 4 and Figure 5. For example, Figures 4 and Figure 5 show that the numbers of residential and commercial consumers connected to the bus 10 at 04:00 pm are 400 and 20, respectively.

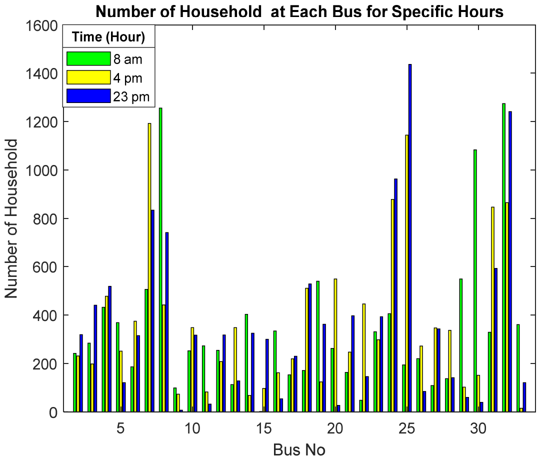

Figure 4. Number of residential consumers randomly assigned to buses for different time zones

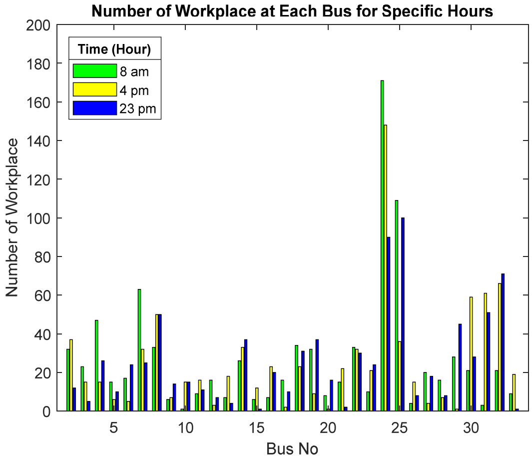

Figure 5. Number of randomly assigned workplace consumers belonging to different buses

Table 1 shows the hourly demanded power values, line power losses, the lowest bus voltage level in the case of TSs (33, 34, 35, 36, and 37) are constant. Table 2 and Table 3 show the analysis after reconfiguration under the same loading condition.

Table 1. Power losses, min bus voltage and power factor results before optimization algorithm

Time interval	Initial open switches	Source power $\sum P_{gen} + jQ_{gen}$ (MW + jMVAr)	P,F. of feeder cos (ϕ)	Demand power $\sum P_{load}$ $\sum Q_{load}$ (MW + jMVAr)	P.F of All Buses cos(ϕ)	Total power losses $\sum P_{loss} + jQ_{loss}$ (kW + j kVar)	Minimum voltage V_{min} (pu)	Bus number for V_{min}
00	33-34-35-36-37	1.6497+j1.0115	0.8525	1.6171+j0.9897	0.8529	32.5430+j21.7297	0.9613	18
01	33-34-35-36-37	1.5059+j0.9255	0.8520	1.4773+j0.9060	0.8525	28.6630+j19.4366	0.9634	18
02	33-34-35-36-37	1.4280+j0.9180	0.8412	1.4000+j0.8990	0.8415	28.0241+j18.9887	0.9654	18
03	33-34-35-36-37	1.3075+j0.8695	0.8327	1.2882+j0.8566	0.8327	19.3517+j12.8119	0.9747	18
04	33-34-35-36-37	1.0486+j0.6928	0.8343	1.0338+j0.6828	0.8344	14.7896+j10.0443	0.9743	18
05	33-34-35-36-37	1.0502+j0.7016	0.8315	1.0351+j0.6914	0.8316	15.1363+j10.2414	0.9733	18
06	33-34-35-36-37	1.0707+j0.7353	0.8243	1.0562+j0.7256	0.8242	14.5355+j9.6915	0.9744	18
07	33-34-35-36-37	0.8354+j0.6029	0.8109	0.8249+j0.5957	0.8107	10.5579+j7.1475	0.9795	18
08	33-34-35-36-37	0.8285+j0.6198	0.8007	0.8196+j0.6139	0.8004	8.8613+j5.8548	0.9807	18
09	33-34-35-36-37	1.3232+j0.8713	0.8352	1.2995+j0.8555	0.8353	23.7048+j15.8390	0.9672	18
10	33-34-35-36-37	1.4659+j0.9582	0.8370	1.4424+j0.9427	0.8371	23.5776+j15.5505	0.9698	18
11	33-34-35-36-37	1.6630+j1.0686	0.8413	1.6291+j1.0461	0.8415	33.9014+j22.5186	0.9619	18
12	33-34-35-36-37	1.4154+j0.8616	0.8542	1.3940+j0.8473	0.8545	21.3849+j14.2569	0.9674	18
13	33-34-35-36-37	1.7255+j1.0686	0.8502	1.6882+j1.0438	0.8506	37.2802+j24.8017	0.9632	18
14	33-34-35-36-37	1.5444 +j0.9374	0.8549	1.5168+j0.9193	0.8552	27.6037+j18.1285	0.9650	18
15	33-34-35-36-37	1.6123+j1.0096	0.8475	1.5751+j0.9846	0.8480	37.2410+j24.9216	0.9580	18
16	33-34-35-36-37	1.6716+j1.0781	0.8404	1.6356+j1.0539	0.8406	36.0052+j24.2321	0.9605	18
17	33-34-35-36-37	1.7394+j1.0970	0.8458	1.7078+j1.0759	0.8461	31.5690+j21.0575	0.9634	18
18	33-34-35-36-37	1.6213+j1.0635	0.8362	1.5908+j1.0434	0.8362	30.4644+j20.1238	0.9682	18
19	33-34-35-36-37	2.0866+j1.2335	0.8608	2.0293+j1.1948	0.8617	57.3106+j38.7444	0.9484	18
20	33-34-35-36-37	2.9766+j1.7138	0.8666	2.8778+j1.6480	0.8678	98.8179+j65.7801	0.9376	18
21	33-34-35-36-37	2.4745+j1.4601	0.8612	2.3931+j1.4049	0.8624	81.3949+j55.1986	0.9447	33
22	33-34-35-36-37	2.3571+j1.4633	0.8496	2.2932+j1.4204	0.8501	63.9310+j42.9404	0.9512	33
23	33-34-35-36-37	2.1796+j1.3471	0.8506	2.1196+j1.3069	0.8512	60.0125+j40.2410	0.9478	18

P.F = Power Factor

- ✓ Power factor is assumed 0,90 and 0,71 for household & workspace, respectively.

It is assumed that 80% of the total load is provided by residential buildings and 20% by workplaces.

Table 2. Results after reconfiguration (algorithms are run 100 times)

Time inter.	Run. num	Open Switches Status in Worst Case	Open Switches Status in Best Case (Min. Power Losses)	Source power $\sum (P_{gen} + iQ_{gen})$ MW ve MVar	Active and Reactive Load Demand Power MW ve MVar (Best Switches)	Switch Status in Worst Case P_{Losses} (kW)
00	100	7 12 16 28 35	7 9 14 28 36	1.6385+j1.0061	1.6171+j0.9897	23.5749
01	100	7 17 28 34 35	7 9 14 28 36	1.4962+j0.9204	1.4773+j0.9060	21.1783
02	100	7 14 28 32 35	7 9 14 28 36	1.4190+j0.9139	1.4000+j0.8990	21.1300
03	100	7 10 14 26 30	7 9 14 31 37	1.3027+j0.8676	1.2882+j0.8566	16.5761
04	100	7 14 16 28 35	7 9 14 28 36	1.0435 +j0.6902	1.0338+j0.6828	10.5832
05	100	7 12 28 35 36	7 9 14 28 32	1.0455+j0.6995	1.0351+j0.6914	11.6601
06	100	7 14 32 35 37	7 9 14 32 37	1.0665+j0.7334	1.0562+j0.7256	11.2831
07	100	7 8 14 27 32	7 9 14 28 36	0.8315+j0.6008	0.8249+j0.5957	7.0264
08	100	7 11 14 26 32	7 9 14 28 32	0.8257+j0.6186	0.8196+j0.6139	7.0307
09	100	7 14 32 35 37	7 9 14 32 37	1.3155+j0.8671	1.2995+j0.8555	17.3959
10	100	7 11 14 26 32	7 9 14 32 37	1.4594+j0.9552	1.4424+j0.9427	19.4473
11	100	6 11 14 26 36	7 9 14 32 37	1.6526+j1.0637	1.6291+j1.0461	27.7596
12	100	7 9 14 17 26	7 9 14 17 37	1.4090+j0.8582	1.3940+j0.8473	16.1232
13	100	7 9 13 26 32	7 9 14 32 37	1.7142+j1.0631	1.6882+j1.0438	29.2462
14	100	7 14 35 36 37	7 9 14 32 37	1.5359+j0.9333	1.5168+j0.9193	20.8840
15	100	6 9 14 26 32	7 9 14 32 37	1.6003+j1.0038	1.5751+j0.9846	25.3920
16	100	7 11 14 26 32	7 9 14 28 32	1.6600+j1.0723	1.6356+j1.0539	26.1771
17	100	7 12 35 36 37	7 11 28 34 36	1.7316+j1.0940	1.7078+j1.0759	25.4134
18	100	7 11 26 32 34	7 9 14 32 37	1.6134+j1.0600	1.5908+j1.0434	25.0971
19	100	7 13 17 28 35	7 9 14 28 36	2.0677+j1.2245	2.0293+j1.1948	42.3381
20	100	7 14 35 36 37	7 9 14 32 37	2.9476+j1.6996	2.8778+j1.6480	72.0115
21	100	7 14 17 28 35	7 9 14 28 32	2.4470+j1.4457	2.3931+j1.4049	58.3994
22	100	7 11 14 26 32	7 9 14 28 32	2.3395+j1.4548	2.2932+j1.4204	50.5972
23	100	6 9 14 32 37	7 9 14 32 37	2.1600+j1.3370	2.1196+j1.3069	42.0438

Table 3. Results after reconfiguration (algorithms run 100 times- Continuation of Table 2)

Time Inter.	Switches Status in Best Case $\sum (P_{loss} + iQ_{loss})$ (Min. Power Losses)	Average Power Losses after algorithms run for 100 times P_{Losses} (kW)	V_{min} (pu) for Bus at ith hour	Bus Num. for V_{min} (pu)	S.D.	Elapsed time (Second)		
						Max	Min	Avg
00	21.3520 +j16.3274	21.8516	0.9766	18	0.4031	7.6852	5.4082	5.6011
01	18.8931+j14.3918	19.4407	0.9775	18	0.4616	9.7015	5.4743	5.9834
02	19.0483+j14.9718	19.5299	0.9768	18	0.4045	7.2428	5.3418	5.5603
03	14.5812+j 10.9514	14.7163	0.9773	32	0.3001	7.7373	5.1830	5.5142
04	9.6267 +j.7.3866	9.90460	0.9846	18	0.2212	9.9486	5.1948	6.0087
05	10.4295 +j 8.1591	10.5887	0.9834	33	0.2118	7.4443	5.0765	5.3209
06	10.3388 +j7.8057	10.4222	0.9820	33	0.1918	8.2146	5.1181	5.3281
07	6.5737+j5.0385	6.6639	0.9873	18	0.0933	7.7871	5.0645	5.2317
08	6.1306+j4.6294	6.1861	0.9867	33	0.1300	10.0539	5.0353	5.2397
09	15.9724+j11.5550	16.1387	0.9795	32	0.2944	8.6275	5.2832	5.4225
10	17.0005+j12.5503	17.1973	0.9786	33	0.3569	8.5344	5.2659	5.4122
11	23.5212+j17.6866	23.8736	0.9748	33	0.6751	7.9660	5.2949	5.3922
12	15.0044+j 10.8782	15.1439	0.9811	18	0.1966	7.2723	5.2025	5.4215
13	26.0149+j 19.3057	26.3740	0.9746	32	0.6384	10.1245	5.3507	5.6314
14	19.0395 +j14.0074	19.1544	0.9786	33	0.2631	10.0152	5.3781	5.6765
15	25.1786+j 19.1737	25.2854	0.9738	32	0.0697	7.4857	5.2737	5.4013
16	24.3465+j18.4817	24.5099	0.9750	33	0.3038	7.6425	5.3541	5.5604
17	23.7749+j 18.0904	24.0334	0.9736	18	0.4051	7.6991	5.4027	5.5604
18	22.5594+j 16.5574	22.7618	0.9769	32	0.4114	7.5880	5.3837	5.5077
19	38.4495+j 29.7104	39.1334	0.9677	18	0.7637	9.1774	5.4699	5.7545
20	69.7703+j 51.5478	69.9169	0.9603	32	0.4361	7.6995	5.5646	5.8670
21	53.9331+j40.7144	54.6395	0.9628	32	0.8800	9.1527	5.5681	5.7851
22	46.3337+j 34.4397	47.1403	0.9651	32	0.8223	7.5756	5.4565	5.6366
23	40.3644+j 30.1640	40.6439	0.9671	33	0.4151	7.4551	5.4465	5.5992

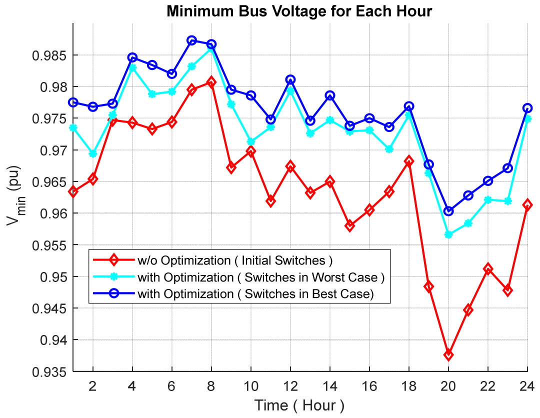

Figure 1. Change of 33 busbar distribution system's minimum voltage value at buses based on hourly basis before and after reconfiguration.

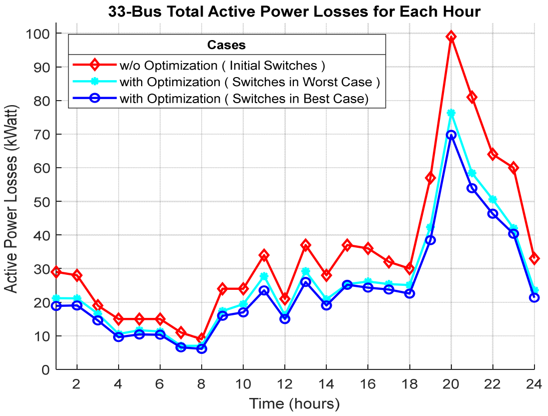

Figure 7. 33-bus system line losses obtained on an hourly basis for the best and worst switching conditions before and after configuration.

The lowest voltage level is calculated as 0.9376 p.u at the bus 18 at 20:00 before reconfiguration. Different switching configurations are observed to form in the daily reconfiguration process performed on an hourly basis. After reconfiguration, the bus 32 is found to have the lowest voltage level with the value of 0.9603 p.u. daily. Upon examining the line losses at the end of 24 hours, it is observed that the switching configuration of the line remains unchanged. Furthermore, the total active power loss in the line is 836.6615 kWh before reconfiguration and reduces to 578.2372 kWh after reconfiguration. The average reduction in active power loss is determined to be 30.8876%, with the highest improvement rate of 37.73% occurring at 07:00 a.m. The bus voltage levels and active line losses before and after optimization are shown in Figure 6 and Figure 7, respectively.

5. CONCLUSION

In this study, the reconfiguration of the 33-bus electrical distribution system is examined using the SMA. Hourly load profiles belonging to residential and commercial consumers are utilized. Using these load profiles, the numbers of consumers connected to the buses are randomly assigned, and the system was reconfigured on an hourly basis. Hourly analyses reveal that the switching positions vary, resulting in a 30% reduction in grid losses by selecting optimal switching positions. Furthermore, improvements have been achieved in bus voltage levels. The average solution time for the optimization process is approximately 6 seconds.

As a result, choosing appropriate switching positions in the distribution grids using optimization algorithms will enable the grid to transmit energy in a more stable, economical, reliable, and uninterrupted way. The reconfiguration of distribution grids not only according to seasonal loads or peak loads but also hourly basis according to the load change in the grid has been found more effective for reducing losses and increasing voltage stability. This study suggests performing hourly reconfiguration based on optimization in the grid where bus load change is high. Future research can focus on extending the proposed methodology to larger and more complex distribution networks, incorporating real-time data and adaptive optimization techniques to enhance system performance.

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