Reducing Power Losses and Improving The Voltage Profiles of Akure Distribution Network using Compensators

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***Abstract*— The power distribution losses of Nigeria power systems are very high, due to this, the distribution power network of Akure Township in Ondo state of Nigeria was considered in this work to see how the high losses can be mitigated and at the same time improve the voltage profiles. With the aid of NEPLAN (Power System Analysis Software), the entire network was simulated and analysed before and after introduction of compensators. The voltage profiles of all the feeders as well as power losses on the existing system and when compensators were introduced were evaluated, the size and location of the compensators were also determined for all the feeders considered. The results show that the power losses on the existing network to be 24.89 MW. With the Installation of compensators and new substations the power losses reduced to 18.3 MW. It was also observed that the voltage profile of all the feeders of the existing network fall out of acceptable limit but this was corrected with the aid of installed compensators and new substations**. (*Abstract*)

Keywords— *Compensators; Distribution Power Losses; New Substations; Voltage Profile* **(key words)**

I. INTRODUCTION

Akure Distribution Network in Ondo State of Nigeria is situated at Longitude 5° 12' East and Latitude 7 ° 18' North. The Akure township distribution network contains all the components and facilities that distribute electrical energy being supplied to about 75,000 consumers in the Akure community from the National Control Centre, Oshogbo. Benin Electricity Distribution Company (BEDC) is the Distribution Company (DISCO) in charge of Akure network. Fig. 2 shows that the 132/33/11 kV, the main power supply to Akure Township originated from 132 kV bus at Osogbo. Akure has two groups of 33/11 kV distribution substations namely; Oba-Ile and Ilesha road 33/11 kV substations. Seven numbers of feeders exist according to specific areas. The network as at 2022 consists of a total of 470 distribution transformers. The power distribution network is being confronted with high power losses [1-3] as well as high deviation from acceptable voltage profiles according to [4]. The acceptable regulatory limit of voltage drop on the 11 kV distribution lines should fall within 11 kV±10% according to [5]. Voltage drop outside this range will have serious consequence on the electrical equipment connected. Electrical equipment utilizes electric power at specified voltages. A deviation from this voltage level adversely affects the efficiency, life span and performance of the equipment.

The most efficient losses reduction techniques in distribution systems are: feeder reconfiguration, distributed generation (DG), VAR compensation, and installation of smart metering for non-technical losses [6]. The use of capacitor for adequate compensation is considered in this work.

II. MEHODOLOGY

In order to determine the power loss reduction technique (scheme) for Akure distribution network, heuristic simulation approach was considered. According to [7], heuristic methods are faster and lead to a solution that is near to the optimal solution.

In the search for the optimal loss reduction technique, power flow and the application of the following possible solutions were simulated and tested using NEPLAN (Power System Analysis Software) to obtain losses as well as the voltage profiles of all the feeders. The tested possible h^{th} solutions are: application of reactive power compensators; feeders' interconnection only; feeders' interconnection with application of compensators; and feeders' interconnection and installation of new lines.

A: Evaluating the Application of Reactive Power Compensators to Existing Radial Network

The existing radial network was reinforced with the introduction of compensators at the 33 kV substations as well as on the 11 kV feeders. The load flow of the entire system under this condition was also carried out, the losses of the feeders and the voltage profiles were obtained. In order to identify possible location of compensator, consideration was given to unilateral injection of reactive power into the network to obtain the voltage profile. In addition, the spot where the

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voltage level crosses the minimum permissible voltage is considered as appropriate secondary location for a compensator or a voltage booster (Fig.1). This heuristic search method for appropriate location is termed, in this study, as method of successive voltage horizons; this is with the consideration that the network is radial under maximum loading scenario.

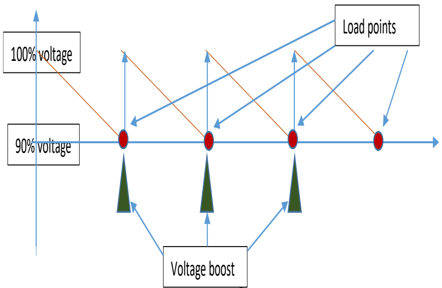

Fig. 1: Location of capacitor to even out voltage profile

$$Q_c = \sum_{i=0}^{n} Q_i \qquad (1)$$

where i is the location for the proposed Compensator, Q_i is capacity of installed capacitor in i^{th} location and Q_c is total capacity of installed capacitors

The existing distribution network for the seen feeders under consideration was simulated using Neplan software to obtain voltage profiles of the different feeders.

The solution conditions are;

(a) Obtaining normal voltage profile in the entire network whereas weak nodes are identified by obtained voltage levels.
(b) Obtaining normal loading of all connecting elements (i.e. it does not exceed normal thermal ratings).
(c) Carrying out economic analysis of scenarios that meet these solution conditions in order to identify optimal techniques or scheme

The summary of this approach is generalized as in equation

$$Z = Min\{\Delta P,' C'\} \qquad (2)$$

Where Z represent the objective, $\Delta P'$ is network losses, which is product of power flow simulation for given test scenario, $C'$is the cost of lost energy and this is derived from obtained $\Delta P'$

$$\forall\, 0.90V_{nom} \le V_i \le 1.1V_{nom} \qquad (3)$$

$$I_{ij} < I_{th} \qquad (4)$$

Where, V_{nom} is nominal feeder's voltage, V_i is voltage at i^{th} node, I_{ij} is current between node i and j, and I_{th} is thermal capacity of feeder and conductor

Hence,

$$h = 'optimal' \;\forall\; \{\Delta P_h', C_h'\} = min \qquad (5)$$

where *h* is the scenario of reinforcement, *h* is going to be optimal when power loss and cost of lost energy is minimum

B: Evaluating the Network in an Interconnected Mode without Compensators

This test scenario evaluates the steady state operation of the Akure network when all the existing open points between feeders were closed without the introduction of compensation. This is depicted in Fig. 2. The total network losses and bus-voltage profiles were obtained by carrying out a load flow simulation on the interconnected network.

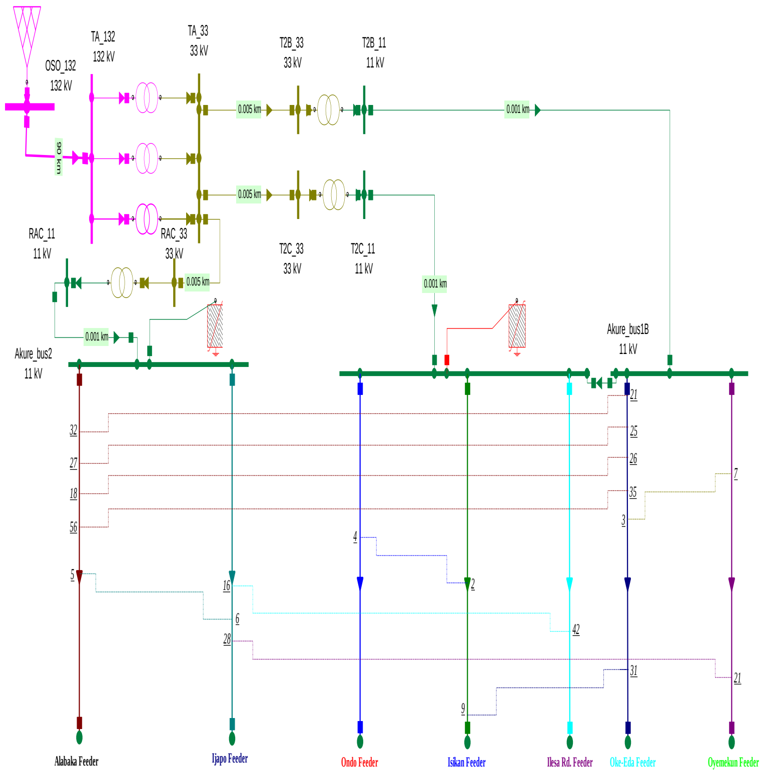

Fig. 2: Single Line diagram of Akure Distribution Network

C: Evaluating the Network in an Interconnected Mode with Compensators

This test scenario is similar to the one described in Section B but with the introduction of compensation. The total network losses and bus-voltage profiles were obtained by carrying out a load flow simulation on the interconnected network. Optimal solutions were obtained considering the size and location of the connected compensators. The optimum location was determined heuristically to give minimum power loss.

III. RESULTS AND DISCUSSIONS

Shown in Table 1 is the range of total active losses and voltage deviation from k mode computation of all the feeders in Akure Network.

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Table 1: Range Statistics of Total Active Losses and Voltage Deviation from k mode computation on all Feeder Networks

Feeder		Uref, kV	loss, kW	%loss	min Udev%	Max Udev%
Ijapo	Min	11.55	-375.539	6.458	-40.9799	1.229
	Mean	11.55	-340.03	7.457	-39.9173	1.3185
	Max	11.55	-297.701	8.25	-38.7392	1.4055
Alagbaka	Min	11.55	-1694.1	12.0	-90.6	-3.7
	Mean	11.55	-1490.1	14.2	-87.3	-3.5
	Max	11.55	-1263	15.9	-85.5	-3.3
Ilesa RD	Min	11.55	-3209.1	33.4	-72.9	-0.9
	Mean	11.55	-2926.2	37.6	-71	-0.8
	Max	11.55	-2656.1	41.7	-69.1	-0.7
Ondo Rd	Min	11.55	-461.176	5.8749	-45.8409	-0.2065
	Mean	11.55	-397.036	7.9774	-43.8677	-0.0265
	Max	11.55	-307.553	9.5034	-41.7955	0.1732
Isinkan	Min	11.55	-679.031	11.0361	-20.8354	2.7569
	Mean	11.55	-593.092	12.4523	-19.8092	2.8313
	Max	11.55	-526.179	14.3181	-19.035	2.9094
Oke Eda	Min	11.55	-791.655	8.217	-57.7447	-1.0899
	Mean	11.55	-700.519	9.5954	-55.787	-0.8893
	Max	11.55	-599.251	10.9957	-53.771	-0.7
Oyemekun	Min	11.55	-171.279	2.5346	-15.756	2.5897
	Mean	11.55	-138.133	3.2391	-14.7966	2.7015
	Max	11.55	-107.676	4.0355	-14.0858	2.7743

A: Obtained Mode Profile of Existing Radial Network After Reinforcement with Capacitors and Substations

Before any reinforcements, the obtained load flow of the entire township network shows that the active and reactive losses are 24.89 MW and 36.21 Mvar respectively. The enormous power loss could be traceable to the cascaded voltage failure at specific 11 kV buses. The load flow did not converge and the voltage profiles of all the different feeders did not fall within the regulatory limit of 11 kV ±10%. This indicates that the network feeders could not be operating without significant load shedding in order to supply at useable quality of voltage to the end users.

Figures 3 to 9 present network diagrams of Alagbaka, Ijapo, Ilesha Road, Isikan, Oke-Eda, Ondo Road, and Oyemekun feeders respectively, showing the locations of proposed capacitors and substations. Figures 10 to 16 show obtainable voltage profiles of the respective feeders before and after reinforcement with capacitors and new substations, when the township network is on load. Fig. 10 shows that Alagbaka feeder, before reinforcement, does not operate within the acceptable voltage limits. The on load voltage level starts to drop below permissible level immediately after node 1. After reinforcement with 15 Mvar capacitors and one new 33/11 kV substation, the feeder's permissible voltage profile of 90% to

110% was obtained. The 15 Mvar capacitor is installed at node 51 and the substation at node 29.

Fig. 11 shows that Ijapo sub-network requires installation of a total 35 Mvar capacitors to provide normal operating voltage profile, out of which 5 Mvar, 25 Mvar and 5 Mvar are installed at load nodes 6, 13 and 28 respectively. Installation of new substation is not necessary for this network.

For Ilesha sub-network, Fig. 12 shows that before reinforcement, the voltage profile falls outside minimum limit immediately after the first node. Normal voltage profile required installation of 20 Mvar capacitors and 33/11 kV substation.10 Mvar and another 10 Mvar are installed in nodes 13 and 27 respectively, while the new substation is installed in node 42.

Fig. 13 shows that the Isikan sub-network requires installation of a total 10 Mvar capacitors to provide normal operating voltage profile. No new substation is required for this network. The 10 Mvar capacitors is installed in node 14.

For Oke-Eda sub-network, Fig. 14 shows that before reinforcement, the voltage profile falls outside minimum limit immediately after the first node. Normal voltage profile required installation of 5 Mvar capacitors and 33/11 kV substation. The 5 Mvar capacitors is installed in node14 while the new substation is installed in node 28.

Fig. 15 shows that the Ondo road sub-network requires installation of a total 22 Mvar capacitors to provide normal operating voltage profile, out of which 6 Mvar, 10 Mvar and 6Mvar are installed at load nodes 5, 10 and 23 respectively. No new substation is required for this network.

For Oyemekun sub-network, Fig. 16 shows that before reinforcement, the voltage profiles falls outside minimum limit immediately after the second node. Normal voltage profiles required installation of 10 Mvar capacitors, which is installed at node 18. No new substation is required for the network.

From the analyses above, it is established that the township distribution network is inadequate by normal mode requirement and needed to be reinforced using capacitors, and new substations.

Consequent to the unacceptable power loss and sagging voltage profile values obtained on the network, alternative power loss reduction schemes were proposed by considering the addition of compensators into this interconnected configuration. The number, location and size of the added compensators are presented in Table 2.

Table 2: The Number, Location and Size of Compensators Added

Partial NW	Node Names	No. of Compensator	Size (Mvar)
33/11kV Section	Akure_bus2	1	20
	Akure_bus1A	1	20
Alagbaka	57al	1	10
	41al	1	10
Ijapo	14ij	1	20
Ilesha	17il	1	10
	36il	1	10
Isikan	14is	1	10
Oke-Eda	27ok	1	10
Ondo Rd.	10on	1	10
	24on	1	20
Oyemekun	18oy	1	15

Table 2 shows that a unit Compensator was required at Ilesha and Oba-Ile 33/11 kV buses each. In total, four units of 20 Mvar, seven units of 10 Mvar and a unit of 15 Mvar Compensators were required at the specified and optimum locations on the Akure 11 kV distribution network.

The total network power loss before and after reinforcements is presented in Fig. 17.

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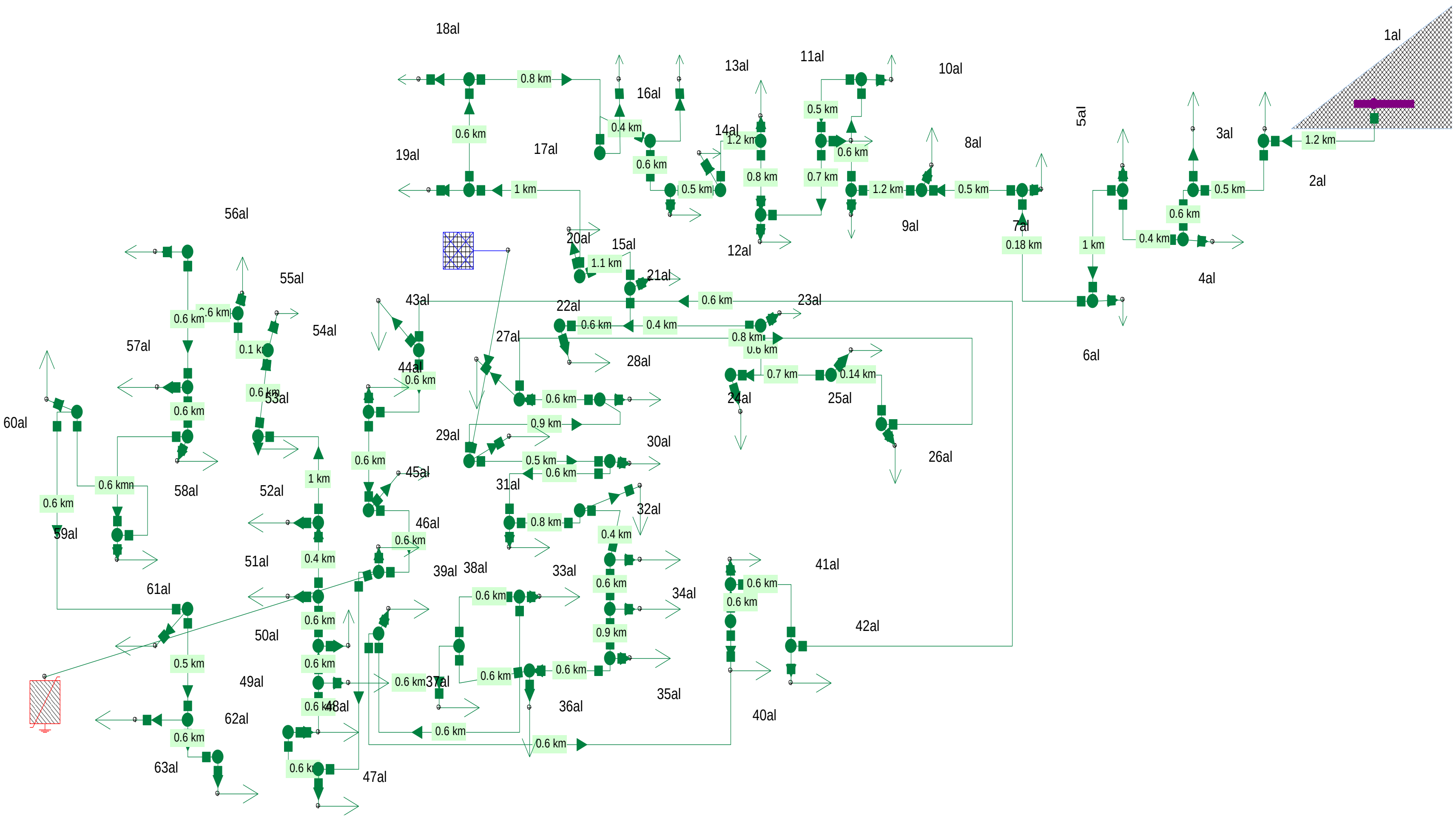

Fig. 3: Existing Alagbaka Network showing new capacitor and sub-station.

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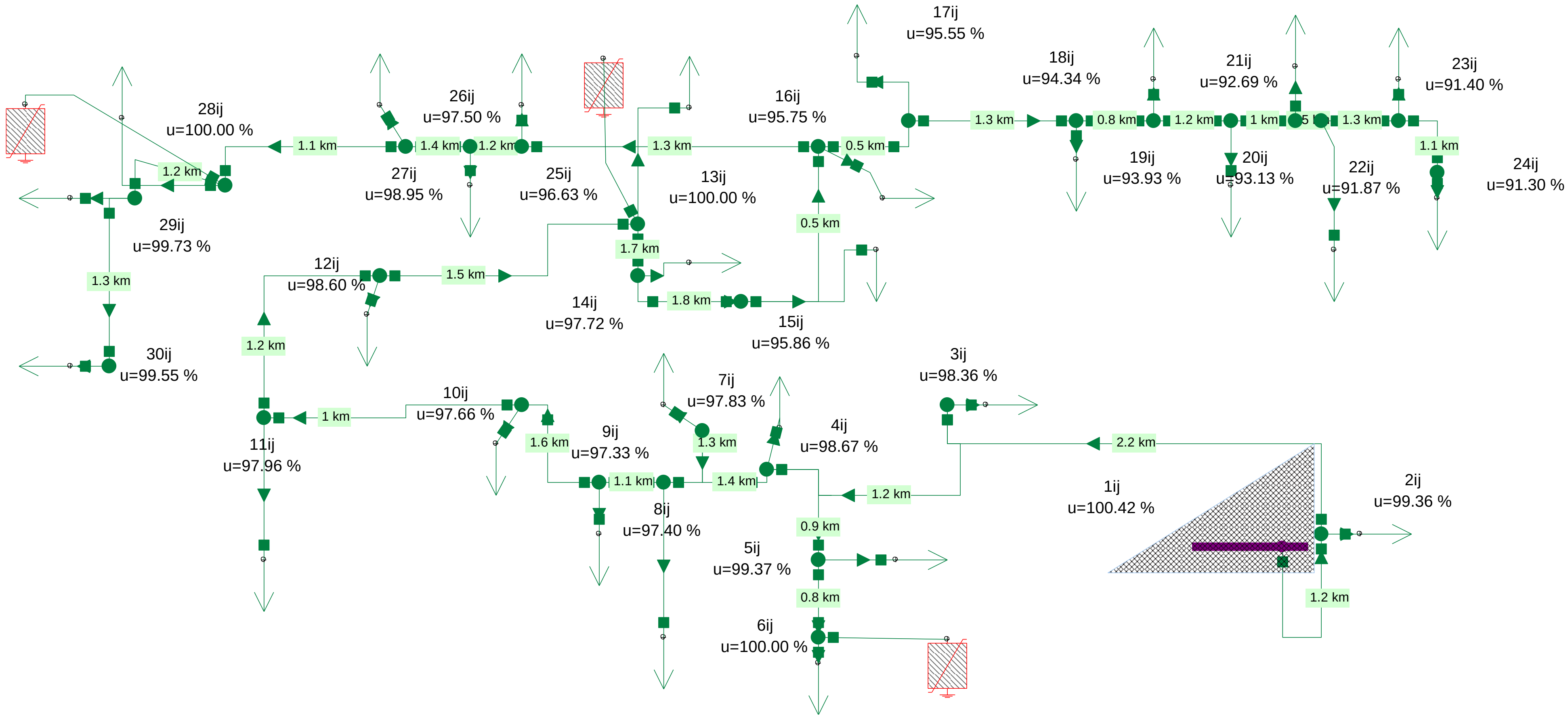

Fig. 4: Existing Ijapo network showing newly installed capacitors.

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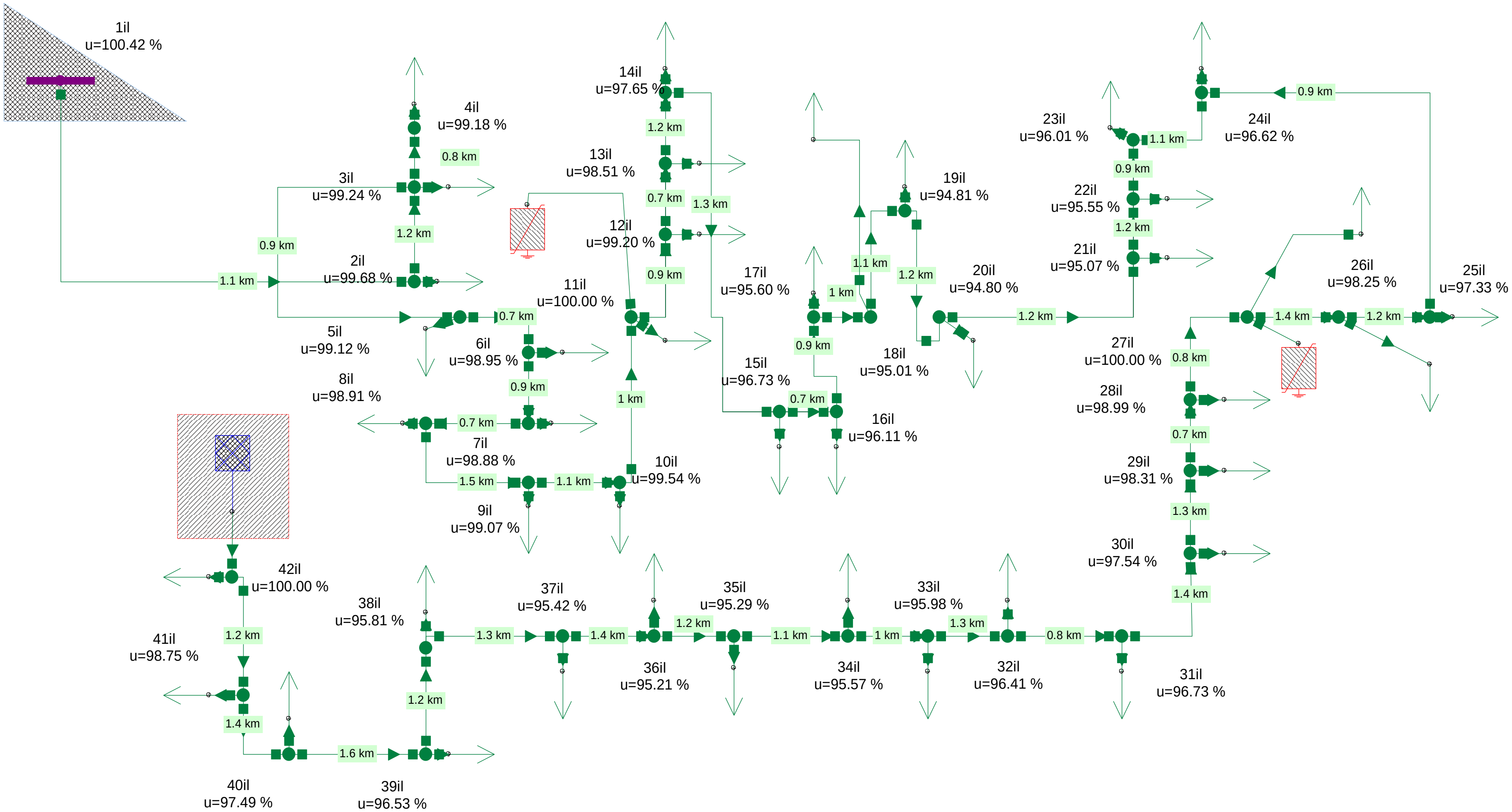

Fig. 5: Existing Ilesha network showing new capacitors and sub-station.

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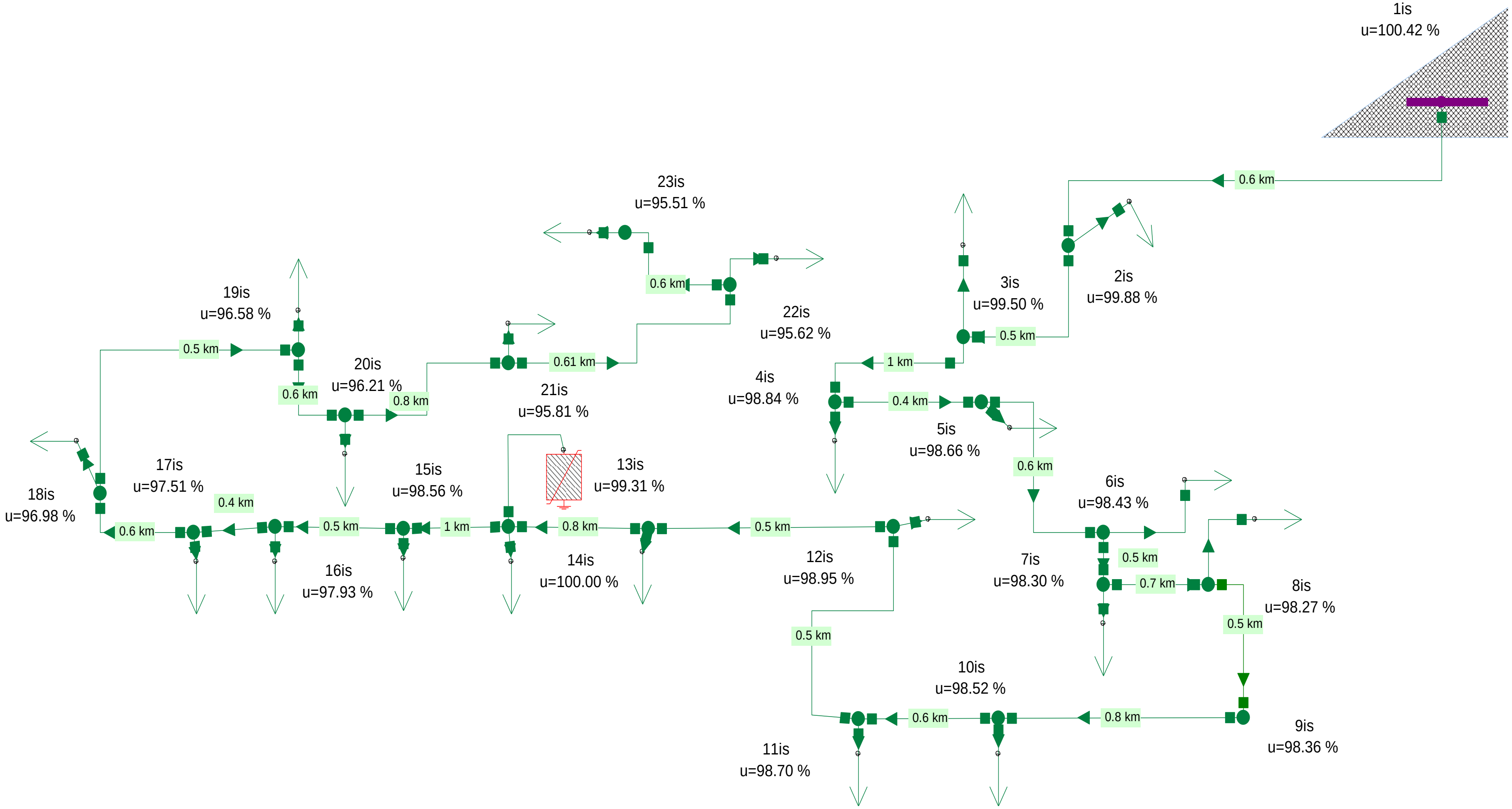

Fig.6: Existing Isikan network showing newly installed capacitor.

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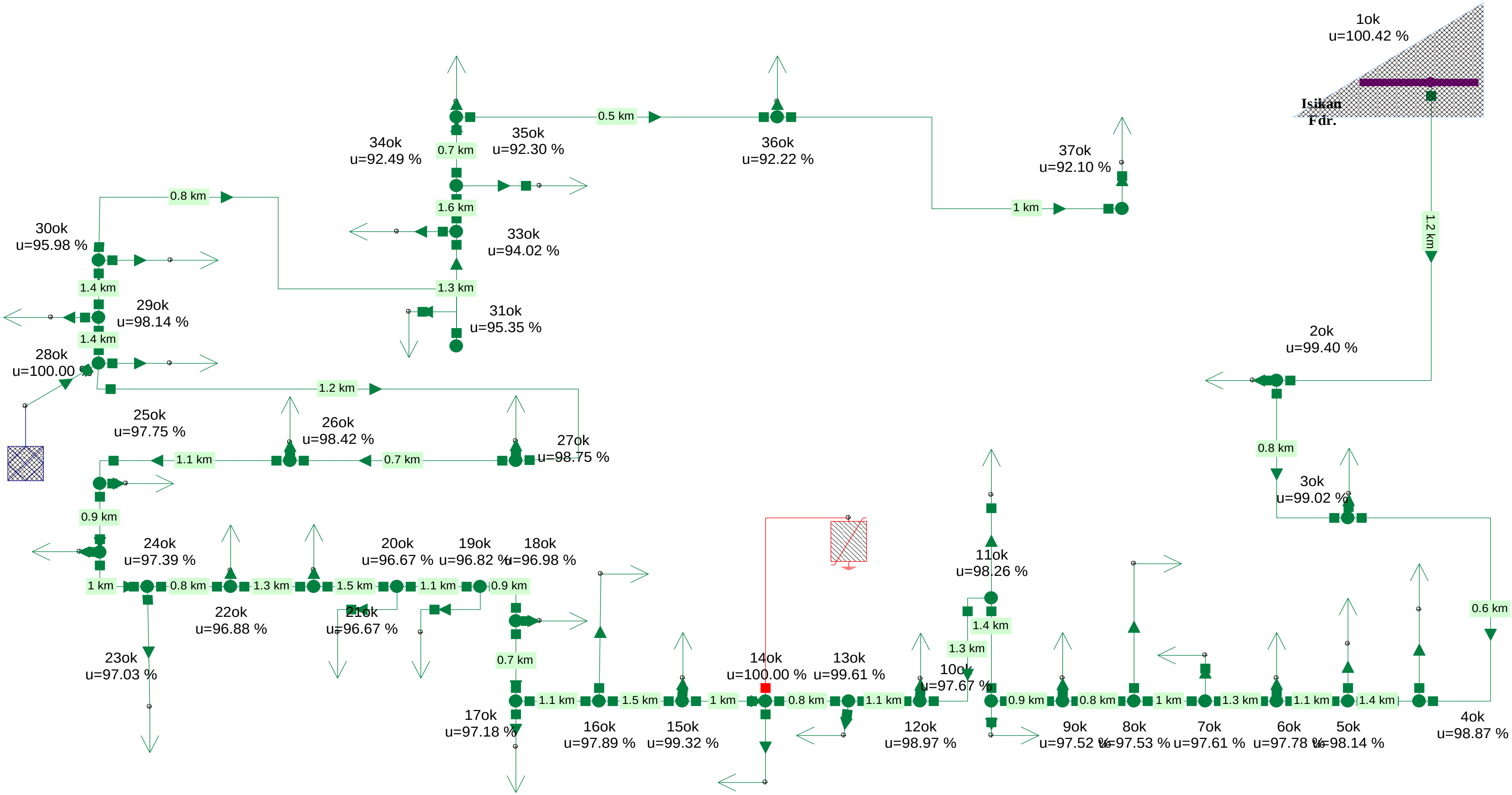

Fig.7: Existing Oke-Eda network showing new capacitor and sub-station.

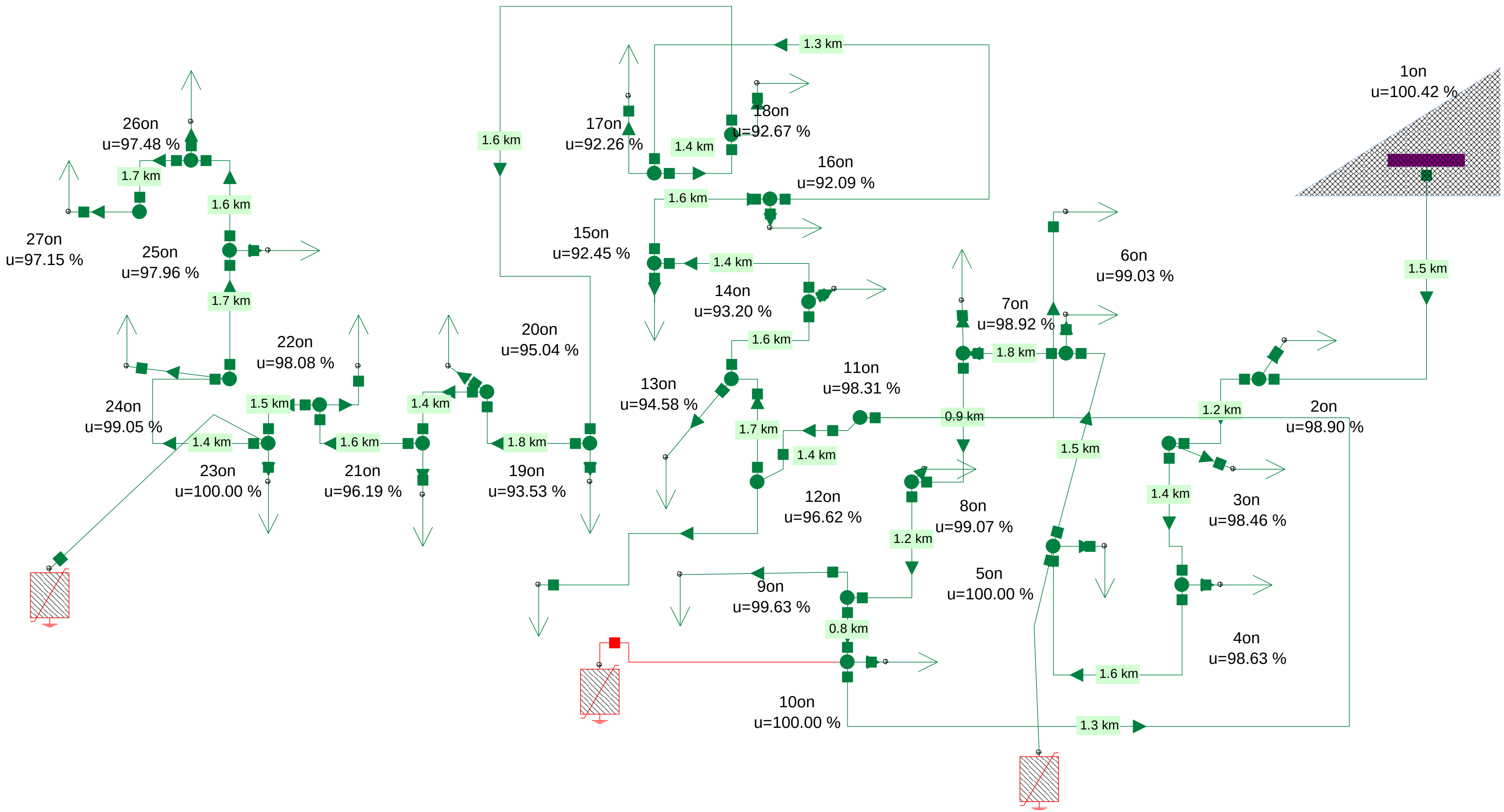

Fig. 8: Existing Ondo road network showing new capacitors.

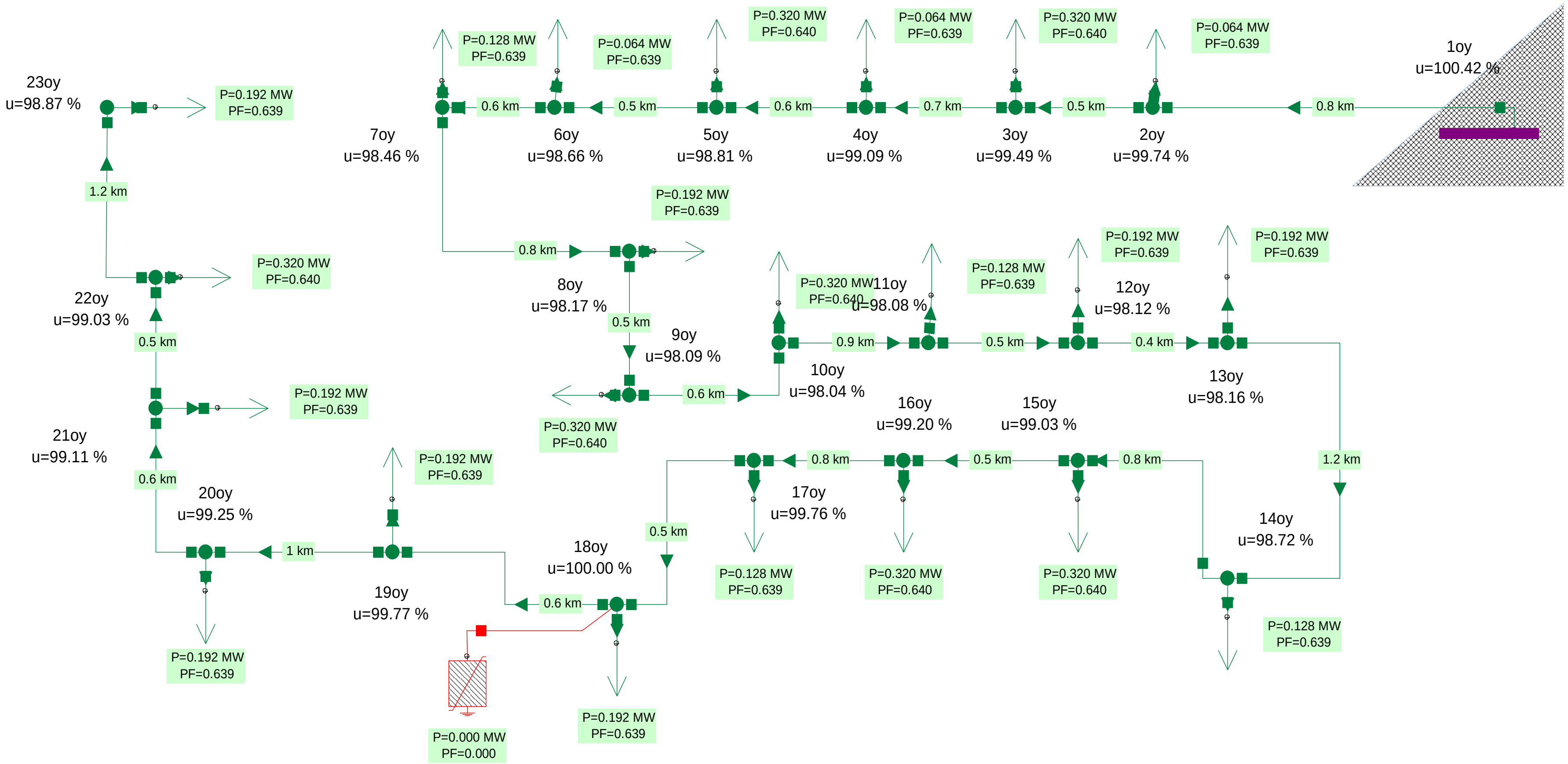

Fig.9: Existing Oyemekun network showing new capacitor.

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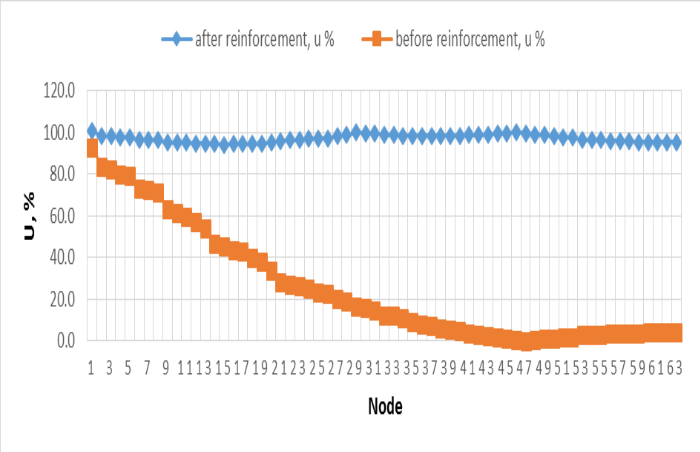

Fig. 10: Alagbaka network voltage profile before and after reinforcements.

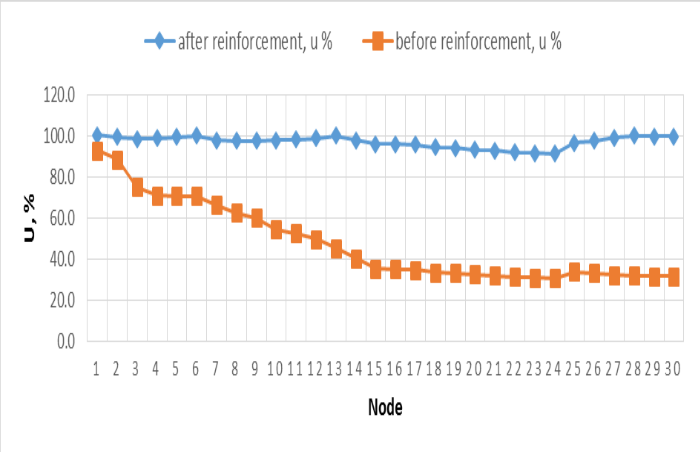

Fig. 11: Ijapo network voltage profile before and after reinforcements.

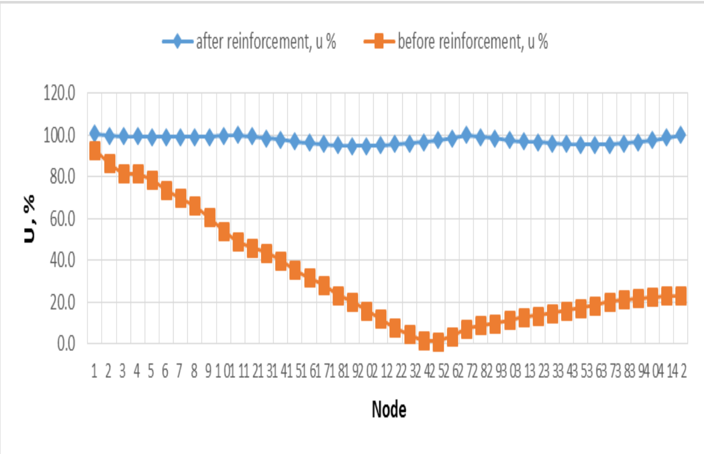

Fig. 12: Ilesha network voltage profile before and after reinforcements.

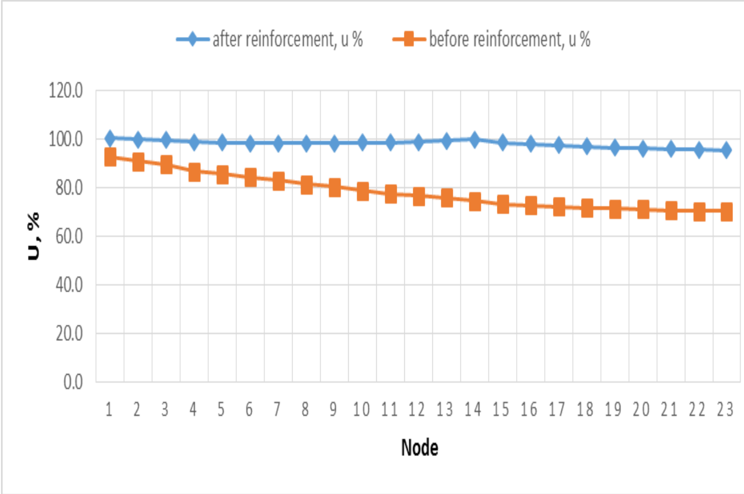

Fig. 13: Isikan network voltage profile before and after reinforcements.

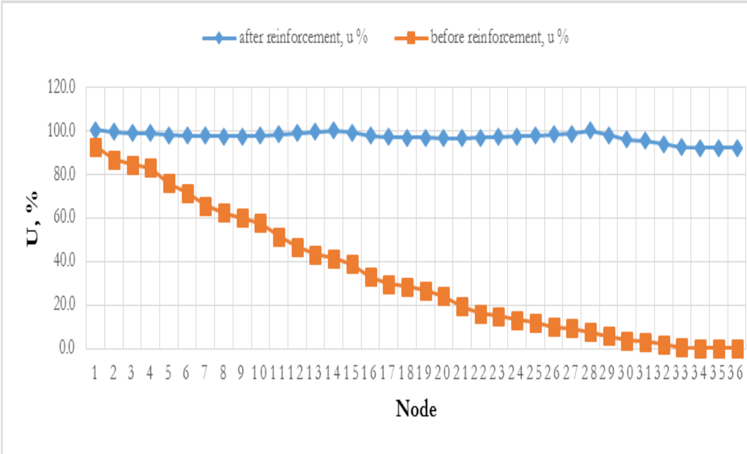

Fig. 14: Oke-Eda network voltage profile before and after reinforcements.

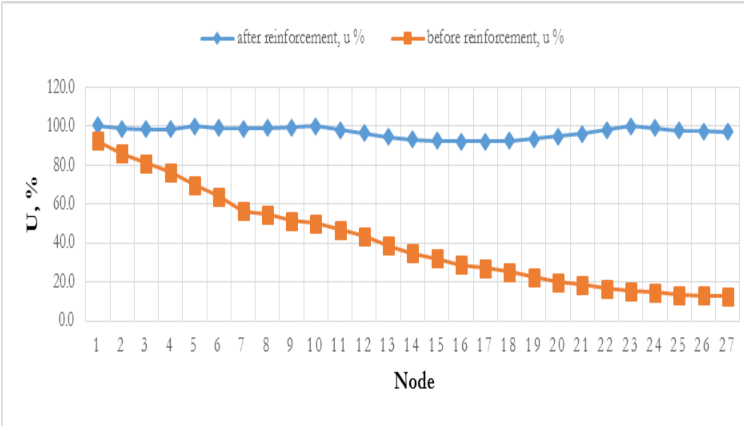

Fig. 15: Ondo road network voltage profile before and after reinforcements.

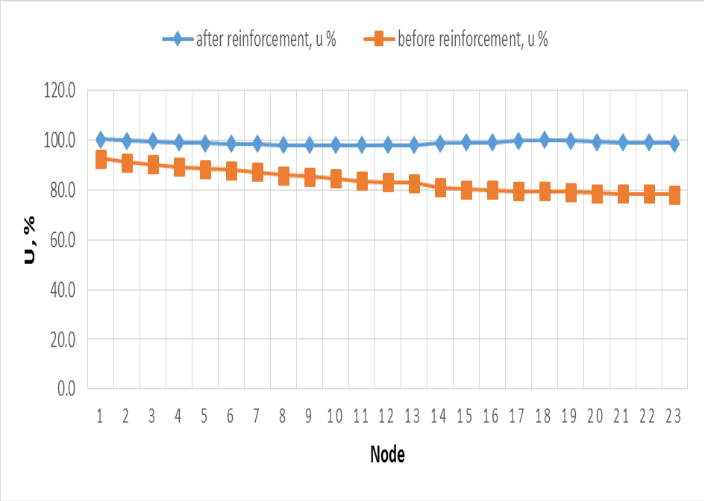

Fig. 16: Oyemekun network voltage profile before and after reinforcements.

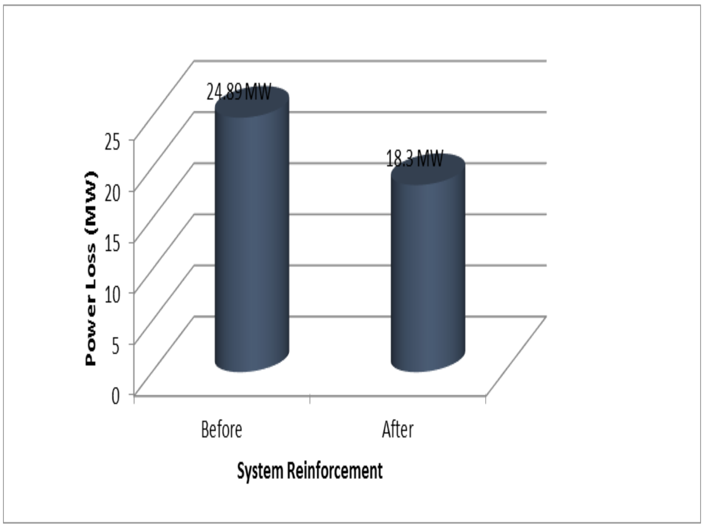

Fig. 17: Total network power loss before and after reinforcements of Radial network.

It could be seen from Fig.10 to 16 that there was significant improvement in the voltage profile on all the feeders. The voltage profiles fall within the acceptable range in all the feeders.

Fig. 17 shows that the existing Akure Township incurred 24.89 MW loss when all the partial network are on-load before reinforcement and reduced to 18.3 MW power loss after reinforcement with compensator.

It can be seen from these analyses that installation of capacitors and new substations can effectively reinforce the network to achieve normal operating profile and Technical loss reduction of 26.5%.

In summary, for the interconnected feeder networks scenario, there are no instances of voltage values exceeding 100% of the normal operating value of 11 kV. The power loss in the township network is 18.3 MW. The existing township network would collapse if permitted to operate under the given peak loads due to critical voltage drops causing huge power losses at all the sub-networks. This interconnection scenario is inadequate to provide normal operating mode of the township network without additional reinforcement measures

CONCLUSIONS

The total active power loss on the existing radial Akure 11 kV network amounted to 24.89 MW after carrying out the load flow operation using NEPLAN software. The load flow operation on the existing system did not converge; the network voltage did not fall within the acceptable operating limits of 90% and 110% nominal voltage of 11 kV.

On reinforcement of the existing radial network with the addition of compensators, the active power loss reduced to 18.3MW per day; there was a daily saving of 6.59 MW of power with this arrangement, the load flow converged and the voltage profiles fell within the acceptable operating limits of 90% and 110% nominal voltage of 11 kV.

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