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Synchronization of Generators for Improved Power Delivery and Cost Effectiveness

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Abstract
In the current economic and political scenario of Nigeria where the economic is clamouring for recession, one ought to embrace such methods in order to limit cost of fuel consumption and generator maintenance in our institutions. In this paper a relatively better cost minimization and better Electrical power system is proposed for the University. The institution runs its generators whether it is full load or simply a load of 25 percent as a standby power. It is suggested that if generatorsare synchronized and connected in parallel, it can not only limit the cost, number of personnel required but also increase the reliability of the system. ETAP software is used for simulation and results show that by adopting this method generation cost can be diminished up to 30 percent which is indeed a colossal figure. Losses and cable parameters were calculated using this software and found this research is veryattainable.

Keywords: Synchronization, Parallel connection, Synchroscope, ETAP.

1.Introduction

There is an extreme electricity power deficiency in Nigeria, andthis has hindered many economic activities with the potential to increase per-capital income of the populace. The demand for power is far higher than the power available to consumers. Frequent outage of power supply occasioned by technical and other losses has led to consumers being vehemently affected in their daily routines(Idoniboyeobu, et al., 2018; Osegi, et al., 2019).Federal University of Petroleum Resources (FUPRE) is also affected by this irregular power supply, to carry on educational activities without any interruption.

FUPRE has its own power network, a small grid as well as alternative power supply sources.The university get its supply from Effurun Transmission Substation 33kV feeder. The incoming goes into the 2.5MVA transformer situated in the university premises. The 2.5MVA transformer step down the voltage from 33kV to 11kV line and distribute power using distribution transformers of different KVA rating to step down voltage from 11kV to 415volt line to line. A total of about six (6) transformers of total capacity of 3,500KVA. In Table 1 presents the various transformer locations and their KVA ratings.

Table 1. Location and Rating of Transformer(s).

S/N	LOCATION	KVA RATING
1	Administrative Block	1,000
2	Collage of Technology	500
3	Collage of Science	500
4	Health Centre	500
5	Hostel	500
6	Tetfund Classroom Blocks	500
Total		3,500

The buildings in the institution are placed in segments; with two or three buildings tired to a generator as their alternative power supply source. These generators are operated at almost 30% or less loads in 10 months of the year and at almost 50% load in remaining two months, specifically May and June. The generator input point for the building in the university is behind each college.There are eight (8) diesel operated generator set of diverse capacity. All the diesel generator set are of Mikano and of Paskins products. The generation voltage of these generator sets is 415V, which is directly fed to the different colleges of the buildings. Table 2. Shows the location and KVA rating of these generators.

Table 2. Location and Rating of Generator(s).

S/N	LOCATION	KVA RATING
1	Administrative Block	500
2	Collage of Technology	500
3	Collage of Science	250
4	Entrepreneurship Building	50
5	Health Centre	135
6	Hostel	100
7	Tetfund Classroom Block 1	60
8	Tetfund Classroom Block 2	50
Total		1,645

With a particular generator being out of service, the sets of building using that generator as power supply source will be in total blackout state. Operating these generators individually incur a lot of losses such as fuel cost, higher maintenance cost and huge lubrication oil cost.Table 3 shows the calculated cost of diesel generators operation monthly.

Table 3: Existing Configuration Generator Diesel Cost.

Location	Capacity KVA	Fuel Consumption Ltr/Hr	Running Hrs/Month	Diesel Drawn/Month	Cost N/Month for N225/Ltr
Admin Block	500	25	150 - 160	3,975	894,375
COT	500	25	150 - 160	3,975	894,375
COS	250	12.5	150 - 160	1,967.5	447,187.7

Entr. Building	50	4.16	150 - 160	661.01	48,727.75
Health Center	135	6.25	150 - 160	993.75	223,593.75
Hostel	100	7.69	250 - 260	1,991.71	448,134.75
Tetfund Block 1	60	4.16	150 - 160	661.44	148,824
Tetfund Block 2	50	4.16	150 - 160	661.44	148,824
TOTAL				14,906.41	3,353,942.25

For continuity of service to all the buildings, the generators are then operated in parallel (synchronized generators operation). With any of the generators out of service, the set of buildings supplied by the same generator will still benefit electricity supply from parallel connected generators.Thus,implementing this method, losses can be reduceddrastically. There are also numerous advantages of this configuration, this includes reduction in terms of diesel cost, reduction in maintenance costamong others [Henderson., 1996; Kim and Kim., 2014; Singh and Kasel., 2007]. Heavy load of blocks for example mechanical lab equipment, and other such sort of massive loads can be operated easily by parallel synchronization method because all the generators are synchronized, and bulk load can be managed. Synchronized generator method also has the ability to meet future expansion of the load. For example, if there is an addition of a new laboratory building in future then to meet this demand, instead of having a separate alternative power source for the said building, the parallel synchronized generator source could be extended to the new building. Table 4, shows the continuous increase in power requirement accounting for future expansion.

Table 4: Power Requirement of the University.

Year	Power Requirement	
	KW	KVA
2016	171	213
2017	215	269
2018	291	364
2019	367	459
2020	535	654
2021	599	749

In parallel operation of generators efficiency of the system will be improved. Less number of personnel is required [Chakraborty, et al., 1993; Sanyi., 2013]. This work therefore presents parallel synchronization of generators to improve power supply and ensure cost effectiveness for a micro-grid such FUPRE power network.

Synchronization arises when two or more generators work together to supply the power load. Since electrical loads constantly vary with time, two or more generators supplying the power need to be interconnected and operate in parallel to handle large number of loads(Barsali, et al., 2002; Thompson., 2012; Wang, et al., 2002). During the process of synchronization of generators or bus bar, the magnitude of voltage, frequency and phase angle are kept constant, in other words these parameters are made the same for all the generators to be synchronized.

Different methods can be used for the synchronization of the alternators, common among these methods are; the dark lamp method, the bright lamp method and the Synchroscope method. The first two methods are not favourable today due to less accuracy and manual operation involved to realize synchronization; these methods required a very skilled person(Gross, et al.,1997; Sandvik., 2019). Synchroscope method with or without microprocessor-based systems are used for the automatic synchronization of the generators in recent time. Also, more recent is the use of power electronic devices to achieve synchronization of generators and bus bars(Bekiroglu and Bayrak., 2009; Schaefer., 2016). The Synchroscope or microprocessor methods and the use of power electronics devices are reliable and easier to manage (Ingle and Halmare., 2014; Shah, et al., 2017). At the core of this method is the device called Synchroscope. It consists of three coils and one moving vane. A pointer is connected to moving vane while the coils are connected to the bus bar and the alternator (generators) which is to be synchronized(Deil-Function Synchroscope,2019). A potential transformer is used to measure the voltage difference, the pointer moves in clockwise and antic clockwise manner and when speed of incoming generator is same to that of bus bar then pointer will stop at vertical point and relays are closed that connect the alternator to the bus bar. With the phase angle between the two voltages different then the pointer of Synchroscope will move, it will move to slower point when the incoming generator is slower; moves towards the faster point if the incoming generator is faster and pointer will stop when the incoming generator frequency is same to that of bus bar. With the last state attainedthen the switch is closed(Bahar, et al., 2018; Ying, et al.,2009). In this paper a customized Synchroscope method wasadopted.

2.Methodology

Real time readings were obtained during generator operation at different months, different times using clamp meter and thus each generator load calculated. The readings of all generators are presented in **Tables 5 - 6**at different times and days.

Table 5: Generator Reading Date; 25/01/2020 Time; 1:30

ID	ADM BLOCK 500KVA	COT 500KVA	COS 250KVA	H. CENTRE 135KVA	HOSTELS 100KVA	TETFUND BLOCK 1&2 50/60KVA	ENT 50KVA
R(PHASE)	178	41.6	41	20	18	32	14
Y(PHASE)	171	41.6	57	16	20	22.4	15
B(PHASE)	100	41.6	34	19	14	22.9	12
Total AMPS	449	124.8	132	55	52	78	41
KVA	322.36	89.6	94.77	39.49	37.33	56.0	29.44
Total KVA	668.99						
KW	257.89	71.68	75.82	31.39	29.87	44.8	23.55
Total KW				535.2			

Table 6: Generator Reading Date: 18/06/2020 Time; 1:25

ID	Admin Block 500KVA	COT 500KVA	COS 250KVA	H. CENTRE 135KVA	Hostel 100KVA	Tetfund B1&2 50/60KVA	Entre. Building 50KVA
R	158	48	45	20	20	35.1	15
Y	158.4	48.01	40.9	17	17. 9	32.4	12
B	101	48.1	43.5	21	18	36.7	12
Total AMPS	417.4	144.11	129.4	55	55.9	104	39
KVA	299.67	103.46	92.9	39.49	40.13	74.81	28
Total KVA				678.05			
KW	251.23	82.77	74.32	31.59	32.11	59.85	22
Total KW				542.44			

Theload flow analysis using the Electrical Transient Analyser Program (ETAP) software for simulation is adopted. In ETAP, load flow is carried out using Newton Raphson Method, its take fewer iteration than other method and it is comparatively reliable and powerful.ETAP is also used to calculate the voltage drop and branch losses in cables.

The un-synchronized system where all the generators are working separately at different locations in FUPRE was modelled and simulated in ETAP as shown in **Fig. 1**.

The proposed synchronized system was modelled with all the generators connected in parallel and then load flow simulations were performed on this model. In this model all the generators give supply to a main bus bar, and then different cables emanates from this bus bar and distribute to all the load centres. The ETAP models used include one schemes, i.e., using copper conductor. ETAP model & load flow report for copper conductor have been shown in **Fig. 2**.

Equipment Required for Proposed Solution

(I.) Synchronization panel (II.) Cables of gauge 400 mm^2, 300mm^2 and 240mm^2 to be installed (III.) ATS switches (IV.) Generators to be synchronized (V.) Main bus bar (VI.) Circuit breakers.

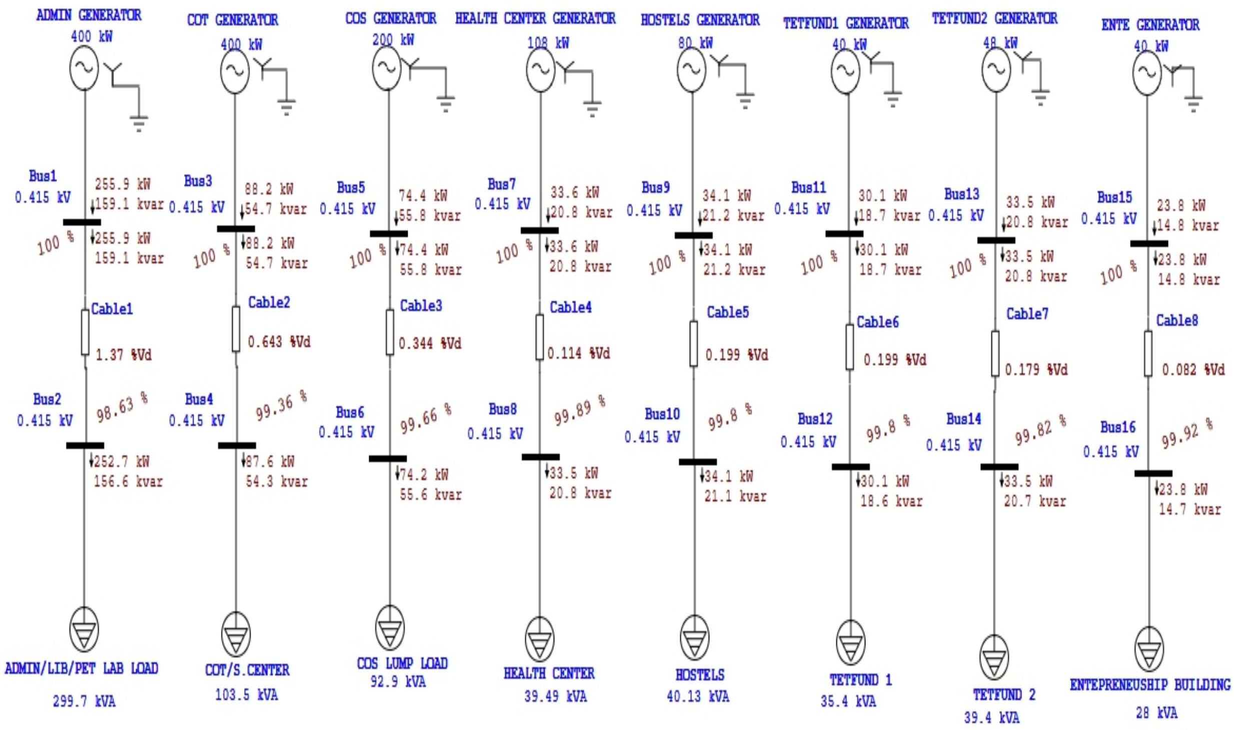

Fig. 1: Load Flow Result for Model of the FUPRE Network in Un-Synchronized Mode

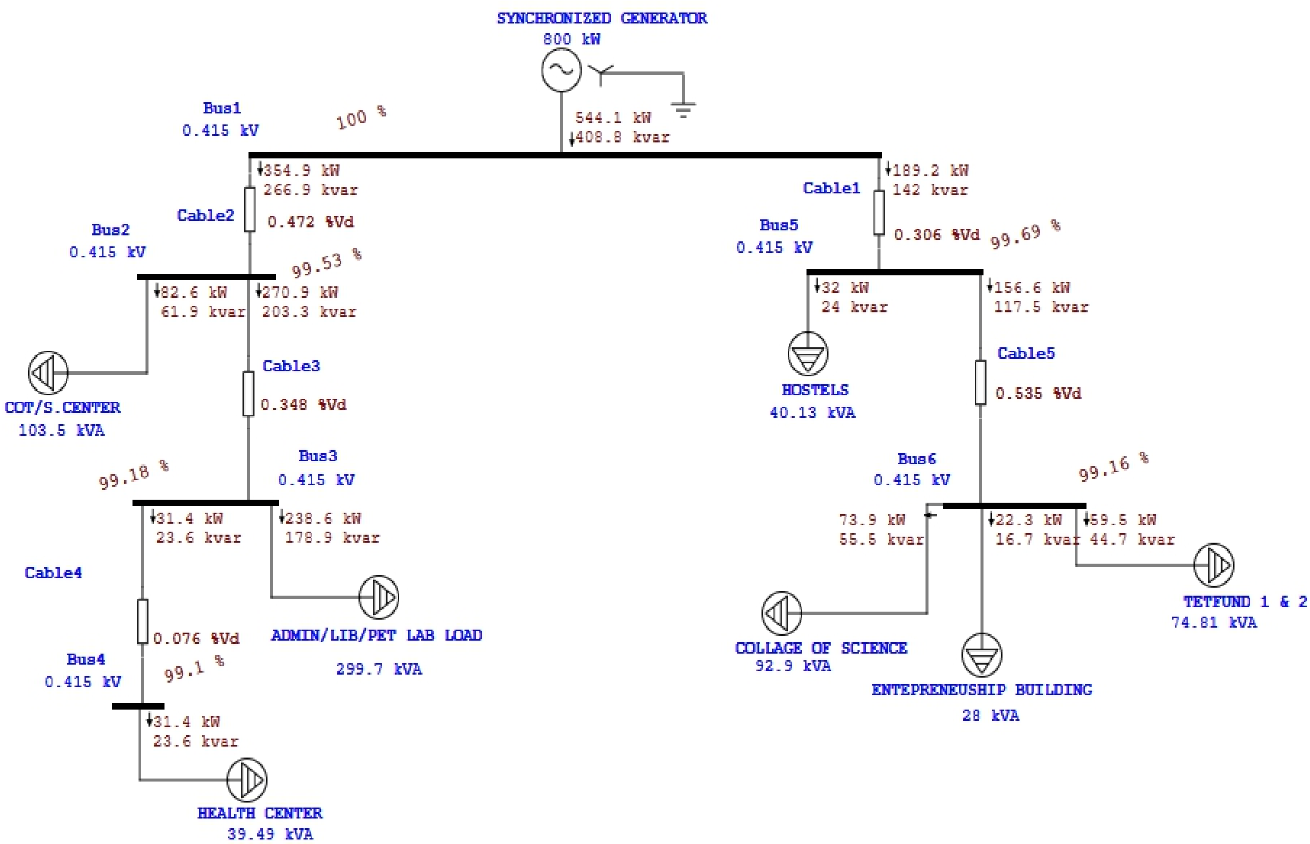

Fig. 2: Load Flow Result for Model of the FUPRE Network in Synchronized Mode

3. Results and Discussion

The result of the load flow simulation with the generators operating individually (unsynchronized) is shown in Table 7, while Table 8, shows the branch losses incurred with the unsynchronized configuration. The same information is presented for the synchronized configuration in Table 9 and Table 10 respectively. The generated power from each source; consumed power by each load and transmitted power by each cable at each bus is shown in Table 11, as reflected from the simulation. The magnitudes as well as the phase angles of the voltages at the various buses are likewise presented. The negative sign attached to the power in the load flow column indicates that power is supplied by that bus.

Table 7 describes the flow of real power and reactive power sharing among different branches in the micro-grid network. The Swing bus has a real power which is 255.9KW and a reactive power which is 159.1KVAR, it can be seen that Bus 2,4,6,8,10,11,14 and 16 are loaded. The negative sign shows that the bus is acting as a sink while others are as a source. Bus 5,6,11 the real power is in a negative sign that shows instead of power flowing to the other branches real power is flowing towards these buses 5,6,11. Same is to the reactive power.

Table7: Un-synchronization of Generators Simulation Results for Newton Raphson Method on a Bus Distribution Systems.

Bus ID	Bus KV	Voltage Mag (%)	Voltage Angle	Generation P KW	Generation Q KVAR	Load P KW	Load Q KVAR	% Loading
Bus 1	0.415	100	O	255.9	159.1	0	0	16.8
Bus 2	0.415	98.63	-0.1	0	0	252.7	156.6	52.4
Bus 3	0.415	100	0	88.2	54.7	0	0	5.8
Bus 4	0.415	99.36	0	0	0	87.6	54.3	9
Bus 5	0.415	100	0	74.4	55.9	0	0	8.1
Bus 6	0.415	99.66	0	0	0	74.2	55.6	16.2
Bus 7	0.415	100	0	33.6	20.8	0	0	6.9
Bus 8	0.415	98.89	0	0	0	33.5	20.8	6.9
Bus 9	0.415	100	0	34.1	21.2	0	0	7
Bus 10	0.415	99.87	0	0	0	34.1	21.1	7
Bus 11	0.415	100	0	30.1	18.7	0	0	8.2
Bus 12	0.415	99.87	0	0	0	30.1	18.6	8.2
Bus 13	0.415	100	0	33.6	20.8	0	0	9.1
Bus 14	0.415	99.82	0	0	0	33.5	20.7	9.1
Bus 15	0.415	100	0	23.8	14.8	0	0	6.5
Bus 16	0.415	99.92	0	0	0	24.8	14.7	6.5
Total				576.7	366	570.5	362.4	183.7

Table8: Un-Synchronization Generator Simulation Results for Newton – Raphson Method on Branch Losses of the Distribution Network System.

Branch ID	From-To-Bus Flow		To-From-Bus Flow		Losses		%Bus Voltage		Vd %Drop inVmag
	P KW	Q KVAR	P KW	Q KVAR	P KW	Q KVAR	From	To	
Cable 1	256	159	-253	-157	3.27	2.54	100	98.6	1.37
Cable 2	88	55	-88	-54	0.572	0.34	100	99.4	0.64
Cable 3	74	56	-74	-56	0.276	0.164	100	99.7	0.34
Cable 4	34	21	-34	-21	0.0387	0.0223	100	99.9	0.11
Cable 5	34	21	-34	-21	0.0686	0.0395	100	99.8	0.20
Cable 6	30	19	-30	-19	0.0605	0.0345	100	99.8	0.20
Cable 7	34	21	-33	-21	0.0606	0.0349	100	99.8	0.18
Cable 8	24	15	-24	-15	0.0207	0.0092	100	99.9	0.08
		Total			4.37	3.18			3.12

Table9: Synchronization of Generator Simulation Results for Newton – Raphson Method on Bus Distribution Network System.

Bus ID	Bus KV	Voltage Mag (%)	Voltage Angle	Generation		Load		% loading
				P KW	Q KVAR	P KW	Q KVAR	
Bus 1	0.415	100	0.0	544.1	408.8	0	0	29.6
Bus 2	0.415	99.53	-0.1	0	0	82.6	61.9	19.3
Bus 3	0.415	99.18	-0.1	0	0	238.6	178.9	14.8
Bus 4	0.415	99.1	-0.1	0	0	31.4	23.6	2.2
Bus 5	0.415	99.69	0.0	0	0	32.0	24.0	10.3
Bus 6	0.415	99.16	0.1	0	0	155.8	116.8	8.3
Total				544.1	408.8	540.2	405.1	84.5

Table 10: Synchronization of Generator Simulation Results for Newton – Raphson Method on Branch Losses of the Distribution Network System.

Branch ID	From-To-Bus Flow		To-From-Bus Flow		Losses		%Bus Voltage		Vd %Drop inVmag
	P KW	Q KVAR	P KW	Q KVAR	P KW	Q KVAR	From	To	
Cable 1	189.2	142.0	-188.7	-141.5	0.6	0.5	100	99.7	0.31
Cable 2	354.9	266.9	-353.5	-265.3	1.4	1.6	100	99.5	0.47
Cable 3	270.9	203.3	-270.0	-202.5	0.9	0.8	99.5	99.2	0.35
Cable 4	31.4	23.6	-31.4	-23.6	0.0	0.0	99.2	99.1	0.08
Cable 5	156.7	117.5	-155.8	-116.8	0.8	0.7	99.7	99.2	0.53
		Total			3.7	3.5			1.74

For this solution all the generators in Administration Block and Collage of Technology (COT) in the university have to be placed on one location then they will be synchronized through a synchronization panel. In this manner all the generators will supply power on a bus bar. The university will get supply from this common bus bar through cables of different gauge depending upon the respective load. Generators will get start according to the load demand, for example if load of the university is 678KVA, then only two generators of 500 KVA will run to meet this demand. Thus, allowing only two generators are required for the total demand instead of eight generators as present. In holiday season for reduced load only one generator is enough to meet the load demand. This solution will result in minimum cost.

Fuel (Diesel) Consumption for the Proposed System

Operating generator individually incur a lot of losses such as fuel cost etc. therefore the author proposed a solution, by connecting generators in parallel combination(synchronization) in other to reduced fuel cost, higher maintenance cost and huge lubrication oil costto a lest 30%. Shown in Table11, is the calculated generator diesel cost of the proposed configuration.

Table 11: Proposed Configuration Generator Diesel Cost.

Generator	Capacity load/day KVA	Fuel Consumption Ltr/Hr	Running Hrs/Month	Diesel Drawn/Month	Cost N/Month for N225/Ltr
1000KVA	692.72	41	154	6,314	1,420,650.00

Price of Cable per Length

For the proposed solution, it is required to install some new cables of different gauges at different locations as shown in the **Fig. 2**. Cables at some locations are already installed. The length, size and location for the new cables are shown in the Table 12. For this solution, cables of three different sizes i.e.,400mm^2 and 300mm^2 and 250mm^{2}have to be installed. The total length of 400 mm^{2}is 180meters, from the proposed powerhouse to COT Block. The total length of 300 mm^2 is 261meters which is from COT to Admin Block. And the total length 240mm^{2}is 665meters which include proposed powerhouse to hostel to COS is 404meters while Admin to health centre is 261meters.The cost comparison for these lengths of 3.5core CU/XLPE/PVC insulated armoured multicore copper conductor given below in tables.

Table 12: Price(s) for the Required Copper Cables

Cable Size	Specification	Current Rating	Length Required	Price/ Meter (N)	Total Price (N)
240mm^2	31/2C X 240mm^2 CU/XLPE/PVC insulated Armored Multicore cable	325.84	225	**65,000**	**14,625,000**
300mm^2	31/2C X 300mm^2 CU/XLPE/PVC insulated Armored Multicore cable	370.34	212	**80,000**	**16,960,000**
400mm^2	31/2C X 400mm^2 CU/XLPE/PVC	435.40	341	**95,000**	**21,945,000**

	insulated Armored Multicore cable	
	Grand Total	**53,530,000**

Total Cost for the Solution

It is better to use a synchronization panel which must have properties like automatic and manual synchronization, load sharing at generators according to the power; it should automatically start and stop generators according to the load, automatically balance work hours (co-aging) etc. For this proposed solution refer synchronization panel is TEKSAN. Generators made by company which produces generators and synchronization panels. Model: TJPS10 Synchronization Panel.

For the proposed solution, we have to put all the generators at one place and then synchronize two through a synchronization panel. Then we have to install some cables that are mentioned above. The total cost comparison for this solution including panel and cable cost is given below in the Table 13. Hence the total cost for this solution is.

Table 13: Total Cost

S/N	Equipment	Price/Equipment
1	Synchronization Panel	1,259,762.50
2	Armored Cable	53,530,000
	Grand Total	54,789,762.50

Pay Back Period

It seen from the real time calculations that enormous cost saving could be achieved in diesel cost every month in a good manner. Adding all the diesel cost savings as well as other reduced cost that will be incurred from the operation of the generators can be helpful to obtain the payback in short period of time. Total saving in current year and approximated savings have been shown in Table 14. It is clear from calculations that 2years six months are required to compensate these costs. So,with synchronized network being installed in January 2021, the amount that could be gotten back in July 2023 is 54,922,914. Hence the payback period is approximately 2year six months.

Table 13: Approximated Savings

Year	Savings
1th year	23,199,507
2rd year	21,199,507
3th year	10,523,900
Grand Total	54,922,914

Conclusion

This research work has been simulated using ETAP software and the load flow analysis result obtained were used for the implementation and planning of synchronized generator configuration in FUPRE. Implementing parallel synchronization technique for generators proved to be advantageous in terms of power supply continuity, reliability, security,and cost saving and effectiveness. Total cost of the solution is 54,789,762 million, total annualproposed diesel expenses is 23,199,507 and total annual expenses of old system is 40,247,307, Total approximated cost saving in 2years six months is 54,922,914with average monthly saving is 1,933,942.25Hence payback period of this solution is 2years six months.

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