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OPTIMUM LOCATION OF DSTACOMS VIA GREY WOLF OPTIMIZER IN A NIGERIAN 330 KV-BUS TRANSMISSION NEWORK

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ABSTRACT

Optimal location of static synchronous compensator (STATCOM) is critical to ensure power loss minimization while meeting the real and reactive power demands in a transmission network. This paper proposes a solution to this non-convex, discrete problem by using the grey wolf optimizer (GWO) as a new metaheuristic algorithm. This algorithm is applied to a 330 kV transmission system to minimize the power loss. The results show that there is a considerable reduction in the power loss and an enhancement of the voltage profile at the buses across the network by reducing the voltage deviation from 1.5283pu to 0.5139pu, representing 66.37% improvement. The system is modelled and simulated in Matlab/Simulation environment. Further comparisons show that the proposed method outperforms all other metaheuristic methods, and matches the best results by other methods.

1. INTRODUCTION

Current developments the likes of advances in renewable energy sources (RES), power electronics, liberalisation of electric power markets, and the need for greener environment have significantly made possible the devolution of power networks. This has led to new sets of problems and opportunities, and the proliferation of distributed generation systems (DGs). FACTS devices have also been recently widely used in improving power flow (PF) and mitigation of power quality (PQ) issues [1].

The synchronous compensator (STATCOM) belongs to FACTS devices family, and is configured using IGBT switches with a frequency range of 2 - 4 kHz, coupling transformer, dc capacitor link, and an external controller as a shunt device [4]. Fundamentally, the voltage source converter generates controllable ac voltage source from the stored energy in the dc capacitor link which appears behind the coupling reactance. Because the dc energy storage is shallow, it is thus not possible to exchange real power with the network. However, reactive power exchange is accomplished by either injecting or absorbing reactive current at the point of common coupling (PCC) through the coupling reactance [2].

Newton-Raphson method is used in this research for the load-flow analysis, because of its faster rate of convergence, efficiency, accuracy and indeed it is a practical method of solving large power network as in [5]. GWO is a nature-inspired metaheuristics technique developed on the basis of the leadership hierarchy and hunting characteristics of grey wolf (*Canis lupus*), details can be found in [6].

2 MATERIALS AND METHODS

This section presents the materials used in realizing the methods in solving the optimisation problem outlined.

2.1 STATCOM control

The STATCOM can operate as an inductor when $|V_i| < |V_o|$ or a capacitor when $|V_i| > |V_o|$. But, there is no DSTATCOM action needed in a steady state operation for $|V_i| = |V_o|$. The exchanges improvise for any voltage deficiency that may have been caused as a result of dynamic reactive load demands or systemic disturbances. Despite the lack of active power exchange, a small phase angle still needs be maintained between the ac supply and the DSTATCOM output voltages to replenish the real power component in order to guard against losses [7].

2.2 Nigerian 330 kV 31-bus grid

This paper utilises the formidable strength of the 330 kV 31-bus network to implement this research. Figure 1, shows the configuration of the grid. The single line diagram of the 330kV Nigerian transmission network was used as a case study and other relevant data. The Egbin Power Station is chosen as the slack bus.

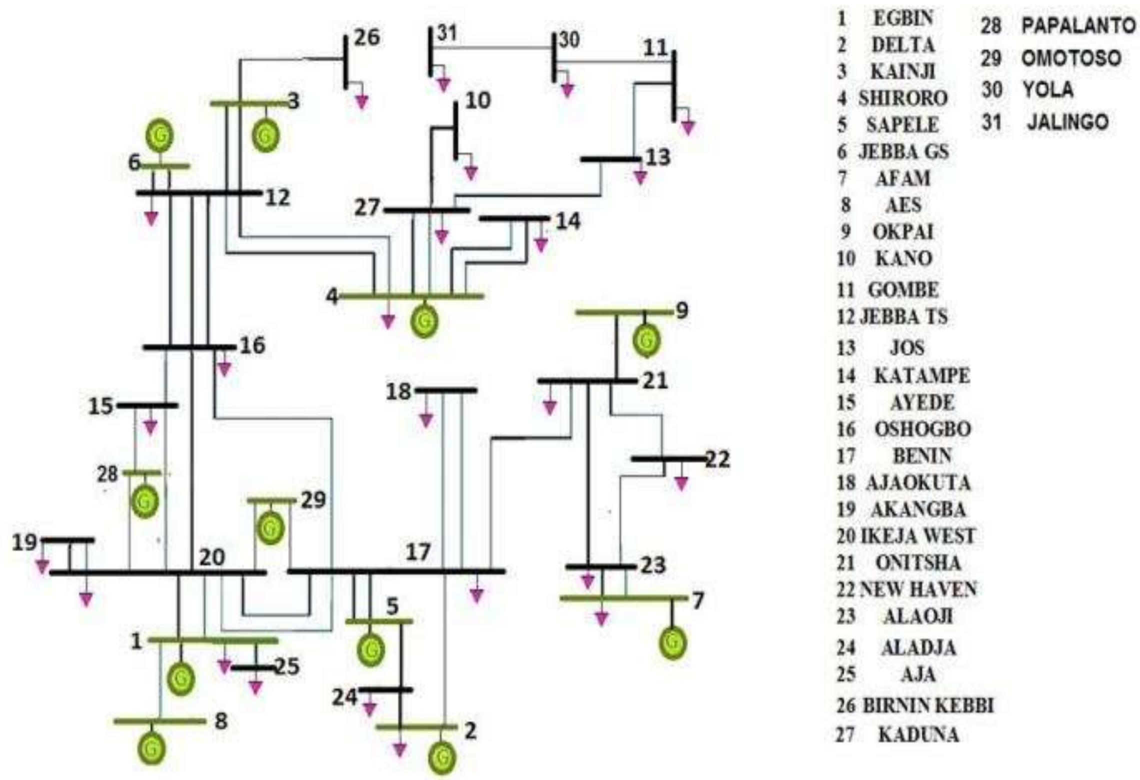

Figure 1: Nigerian 330 kV 31 – Bus Network

2.3 Grey wolf optimizer

The grey wolf optimizer (GWO) is a swarm intelligence algorithm introduced by [12] that does not require any tuning on the part of the user. It employs the two operators for its working: (i) encircling prey, and (ii) hunting. These are explicitly described in [13].

3. RESULTS AND DISCUSSIONS

This section presents and discusses the results so far obtained from the outlined methods. Its advantages over other metaheuristic techniques is also highlighted and compared.

3.1 Problem Formulation

The problem involves identifying the location, the size of STATCOM to be introduced at different nodes of the transmission network while ensuring the operational constraints are met to ensure system integrity.

3.1.1 Objective function

Consider the single line diagram of the 330 kV 31 – bus grid with N – number of generation buses. The real power or I^2R losses between generation buses *i* and *i + 1* is given by

$$P_{i,i+1}^{loss} = \frac{P_{i,i+1}^2 + Q_{i,i+i}^2}{|V_i|^2} R_{i,i+1} \quad (1)$$

The total line loss is the sum of losses in all the line section of the generators is given by

$$P_{i,i+1}^{Tloss} = \sum_{i=0}^{N-1} \frac{P_{i,i+1}^2 + Q_{i,i+i}^2}{|V_i|^2} R_{i,i+1} \quad (2)$$

Where, $P_{i,i+1}$ and $Q_{i,i+1}$ are the real and reactive power flow between buses i and i + 1, in kW and kVAr, $R_{i,i+1}$ is the resistance of the line between busses I and i+1, and V_i is the voltage at bus i.

Similarly, the reactive power loss in the line section between buses i and i+1 is given by

$$Q_{i,i+1}^{loss} = \frac{P_{i,i+1}^2 + Q_{i,i+i}^2}{|V_i|^2} X_{i,i+1} \quad (3)$$

Where, $X_{i,i+1}$ is the resistance of the line between busses I and i+1.

The objective is to minimize the total real power loss incurred by placing the STATCOM at optimal bus locations and choosing the optimal sizes of the STATCOM. With the addition of the STATCOMs, (2) becomes

$$P_{STAT}^{Tloss} = \sum_{i=0}^{N-1} \frac{(P_{i,i+1} - \alpha_{PSTAT} P_{STAT,i+1})^2 + (Q_{i,i+1} - \alpha_{QSTAT} Q_{STAT,i+1})^2}{|V_i|^2} R_{i,i+1} \quad (4)$$

Where α_{PSTAT}, α_{QSTAT} are the real and reactive power multipliers, set to 1 if STATCOM is connected, and 0 if STATCOM is not connected.

$P_{STAT,\ i+1}$, $Q_{STAT,\ i+1}$ are the sizes of the STATCOM or active and reactive power injections at bus i+1 in KW and kVAr, respectively.

3.1.2 Constraints

The inequality constraints of the problem are given by:

- The voltage at each bus should be well within the permissible limits:

$$V_{i,\ min} \leq V_i \leq V_{i,\ max} \quad (5)$$

- The size of individual Generator unit is to be maintained within the set limits [14].

$$S_{STAT,i,\ min} \leq S_{STAT,i} \leq V_{STAT,i,\ max} \quad (6)$$

3.2 Simulation studies

After the simulation, maximum number of iterations reached was 50. And the maximum numbers of STATCOMs installed were 2, at buses 13 (Ayede) and 28 (Birnin Kebbi) with installed capacities of; 718.3158 + j607.5794, and 933.42 + j789.225, respectively. Table 2, presents the voltage magnitudes in a Nigerian 31-bus system, both before and after STATCOM placements.

Buses 10, 11, 13, 14, 17, 19, 24, 25, 28, 29, 30 and 31 violated the voltage limit which is one of the constraints. These violations were successfully corrected and the voltages brought back within limit after the optimal installation of the STATCOMs using GWO, as shown in Table 3. and without STATCOM. Figure 3, shows the representation of reactive power loss in the system, with and without STATCOM.

Figure 2, portrays the graphical representation of these voltages profiles with and without STATCOM. Figure 3, shows the representation of reactive power loss in the system, with and without STATCOM.

Table 2: Voltage Magnitude in a Nigerian 31-Bus System

Bus Number	BEFORE PLACEMENT (pu)	(kV)	AFTER PLACEMENT (pu)	(kV)
1	1.0200	336.6000	0.9947	328.2510
2	1.0300	339.9000	0.9898	326.6340
3	1.0500	346.5000	1.0025	330.8382
4	1.0500	346.5000	0.9996	329.8680
5	1.0500	346.5000	1.0133	334.3956
6	1.0300	339.9000	0.9947	328.2510
7	1.0300	339.9000	0.9927	327.6042
8	1.0500	346.5000	0.9937	327.9276
9	1.0500	346.5000	0.9996	329.8680
10	1.0737	354.3210	1.0238	337.8560
11	1.0616	350.3280	1.0208	336.8534
12	1.0372	342.2760	1.0263	338.6645
13	**1.0557**	**348.3810**	1.0359	341.8338
14	1.0685	352.5984	1.0274	339.0526
15	1.0458	345.1140	1.0249	338.2117
16	1.0306	340.0980	1.0100	333.2960
17	1.0836	357.5880	1.0325	340.7342
18	1.0451	344.8830	1.0340	341.2193
19	1.0942	361.0860	1.0331	340.9283
20	1.0303	339.9990	1.0097	333.1990
21	1.0371	342.2430	1.0066	332.1641
22	1.0138	334.5540	0.9837	324.6289
23	1.0217	337.1610	0.9915	327.1838
24	1.0606	349.9980	1.0296	339.7640
25	1.0809	356.6970	1.0299	339.8611
26	1.0384	342.6720	1.0078	332.5846
27	1.0246	338.1180	1.0041	331.3556
28	**0.9020**	**297.6600**	0.9526	314.3448
29	1.0918	360.2940	1.0308	340.1521
30	1.0569	348.7770	1.0260	338.5675
31	1.1237	370.8210	1.0215	337.0798
	1.6335	*339.1474*	*0.3377*	*184.0302*

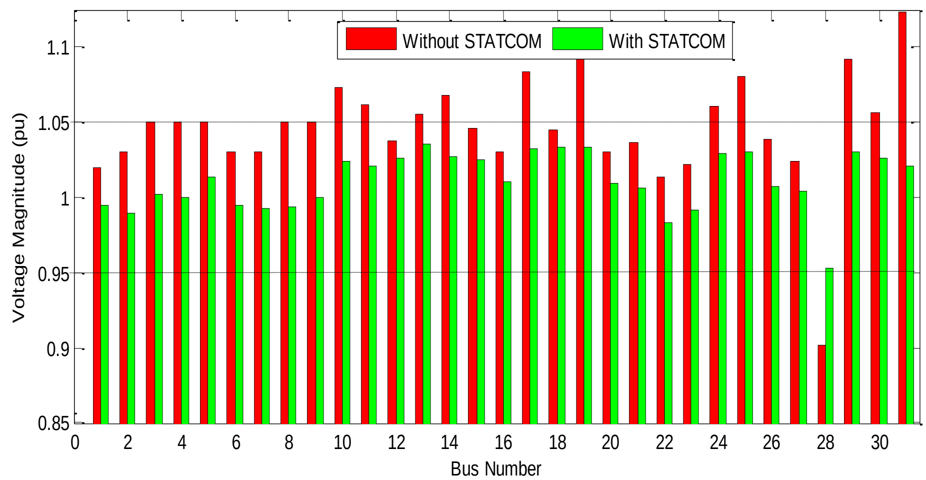

Fig 2: Voltage magnitude with and without STATCOM

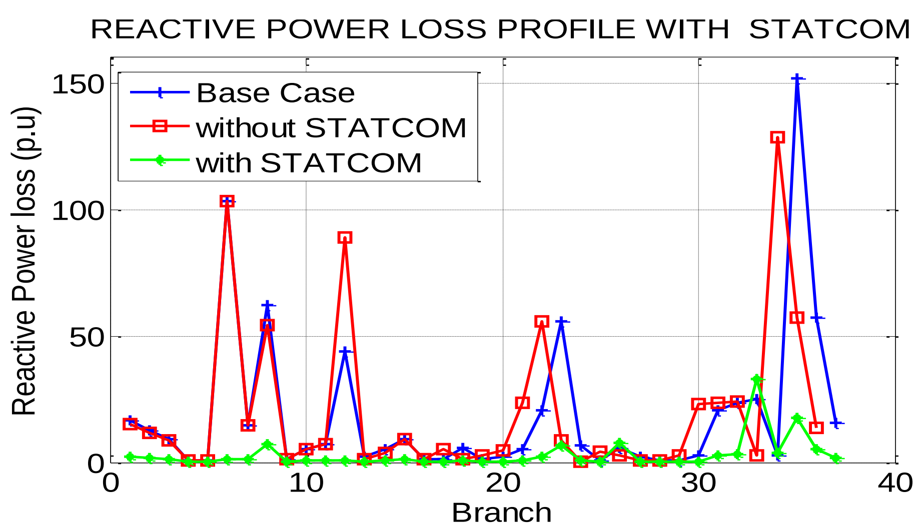

Fig 3: Reactive power loss with and without STATCOM

Table 3: Corrected Violated Bus Voltage Limits by GWO With STATCOM

S/No	Bus No.	Vb(p.u) GWO	Va(p.u) GWO
1	10	1.0737	1.0238
2	11	1.0616	1.0208
3	13	1.0557	1.0359
4	14	1.0685	1.0274
5	17	1.0836	1.0325
6	19	1.0945	1.0331
7	23	1.0606	1.0296
8	24	1.0809	1.0299
9	27	1.0918	1.0308
10	28	0.9020	0.9526
11	29	1.0918	1.0308
12	30	1.0569	1.0260
13	31	1.1237	1.0215

4. CONCLUSION

The optimal deployment of STATCOM for voltage profile improvement is successfully achieved using the Grey Wolf Optimizer technique. The main objective for the optimization process is to minimize voltage deviation of the system while considering the effects of cost management and environmental degradation. The proposed Grey Wolf Optimizer has been seen to efficiently correct voltage profile violations at the specified buses, at fast convergent speed, as a case study of the Nigerian 330 kV 31 – bus network.

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