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MATPOWER as Educational Tool for Solving Optimal Power Flow Problems on a Simulated Nigerian Power Grid

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ABSTRACT: *Power system simulators are viable educational tools widely used in teaching and research in electric power system because power system infrastructures in real life condition cannot be installed in the four walls of University and research centre laboratories except by a way of demonstrators or power system simulators and computer packages. The well known MATPOWER simulation package was utilized to solve optimal power flow problem of 31-Bus Nigerian Grid system to demonstrate its application as an educational tool for solving power flow problem. The Optimal Power Flow (OPF) results of Nigerian power systems revealed that ₦101,548.47 is spent per hour on fueling of various generating units and that there is correlation among the load increment, cost and system losses.*

KEYWORDS: *Matpower, Optimal Power Flow, Virtual laboratory, Educational aid, Matlab*

I. INTRODUCTION

One of the major constraints faced in the teaching of power system analysis courses especially at undergraduate level is the non-availability of real-life power system for demonstration in the laboratory. This makes certain aspects of the course uninteresting to the students since it is full of complex mathematics that may be extremely laborious, error prone, and time-consuming to solve manually. However, with the advent of personal computers, the story is different today. The ability of these modem computers to provide useful information and react to responses has been responsible for its integration into power engineering curriculum [1]. Digital technologies can play a role as tools which afford learners the potential to engage with activities. The use of such tools may extend or enhance their users' abilities, or even allow users to create new ways of dealing with tasks which might also change the very nature of the activity. Hence, integration of computer aided design into the power systems curriculum makes the fields more friendly and meaningful to students.

A number of commercial software packages have been developed for solving power system analysis problems[2]. For example, Power System Simulation for Engineering (PSS/E), Electronic Teaching Assistance Program (ETAP), Power World, Mathematical Laboratory (MATLAB/Simulink), Power System Computer Aided Design (PSCAD), etc, are all graphical user interface enabled and user-friendly software for carrying out time-domain computer simulations of power systems. However, these packages require good modeling and simulation knowledge, and may also be difficult to use for complex and large power systems. In addition, none of these packages allows the user to add new algorithms to it or even change the source code[3]. Other simulation tools that are used for power system analysis include University of Waterloo Power Flow (UWPFLOW) [4], Power System Toolbox (PST) [5] Power System Analysis Toolbox (PSAT) [6], MATPOWER [7], and Voltage Stability Toolbox (VST) [8]. Even though these software use MATLAB as the platform on which they can be run, one special fact about MATPOWER is that being free open source package and its codes could be modified. This is particularly important for researchers and students who are interested in developing and testing novel projects.

II. OPTIMAL POWER FLOW (OPF) FORMULATION

The OPF is used to optimize the power flow solution of Nigerian Grid System by minimizing the objective function, f(x) which is the fuel cost functions or the total cost of generation, subject to power balance (i.e equality constraints), $h_i(x)$ and power limits (i.e inequality constraints), $g_j(x)$. Mathematically, expressed as follow:

Minimize f(x) (the objective function)

Subject to: $h_i(x) = 0, \quad i = 1, 2, 3, \ldots, m$ (equality constraints)

$g_i(x) \leq 0, \quad j = 1, 2, 3, \ldots, n$ (inequality constraints)

There are m equality constraints and n inequality constraints and the number of variables is equal to dimension of vector x.

Study System

The case study for this paper is the Nigerian 330kV power system network comprising of seven (7) generators and 31 buses depicted as in Figure 1.

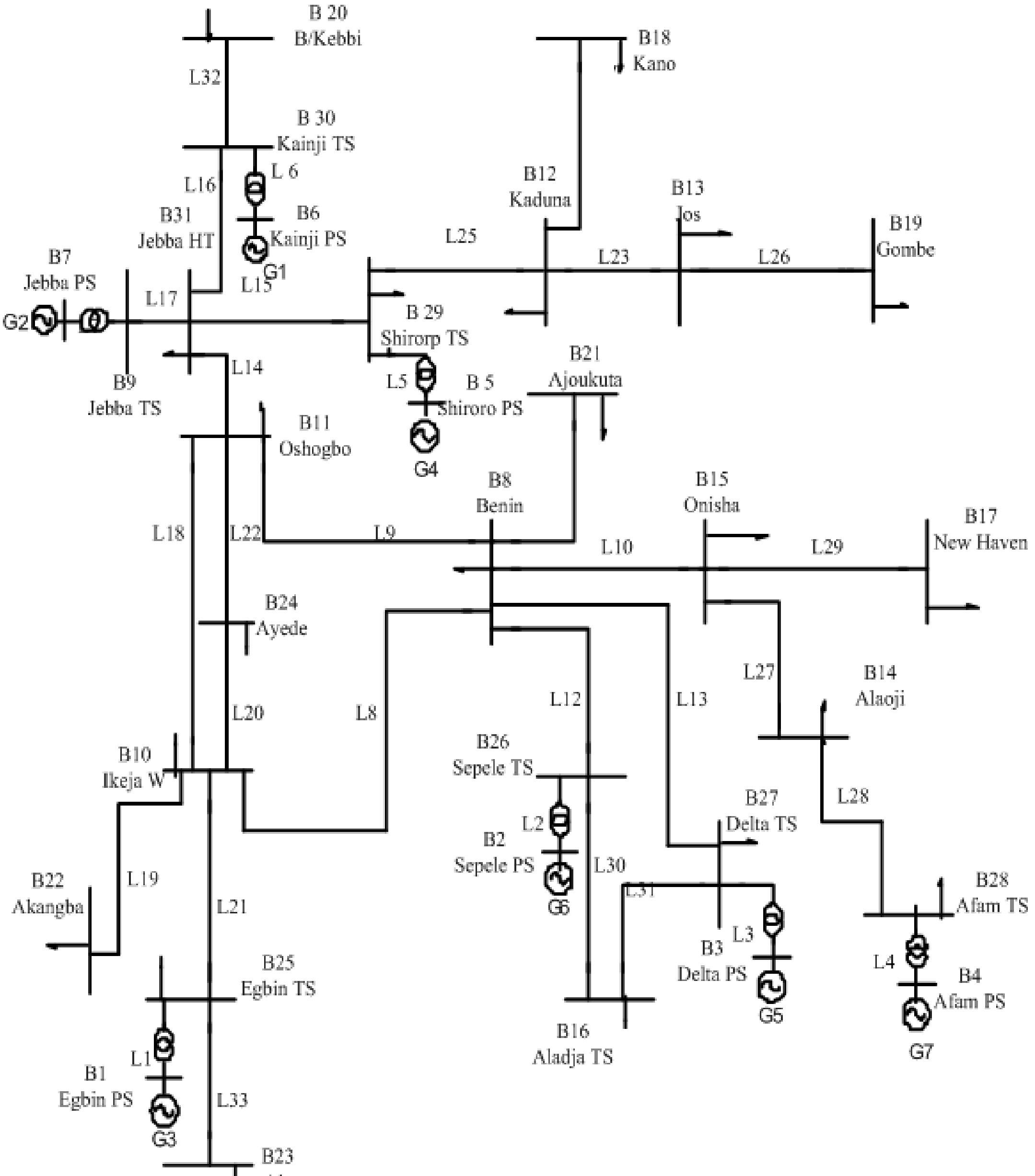

Figure 1: The Nigerian Power Grid System

III. IMPLEMENTATION OF OPF USING MATPOWER

MATPOWER includes several solvers for the optimal power flow (OPF) problem which can be accessed via the runopf function [7]. In addition to printing output to the screen, which it does by default, runopf optionally returns the solution in output arguments:

```
>> [baseMVA, bus, gen, gencost, branch, f, success, et] = runopf(casename)
```

Data Input to MATPOWER

The Nigerian network shown in Figure 1 having the following data tabulated in Tables 1,2,3 and 4 representing the generator data, generator cost function data, branch or line data and bus data respectively were inputted from source [9] to MATPOWER simulation package.

/ **Table 1: Generator Data of 330kV Nigerian Grid System**

Bus No.	Pg	Qg	Qmax	Qmin	Vg	mBase	Status	Pmax	Pmin
1	830.23	0	450	-255	1	100	1	1320	0
2	200	0	450	-250	0.99	100	1	500	100
3	300	0	450	-250	1	100	1	400	30
4	250	0	450	-250	1	100	1	280	0
5	490	0	450	-250	1.03	100	1	600	0
6	350	0	450	-250	1.04	100	1	540	0
7	450	0	450	-250	1.03	100	1	560	0

Table 2: Generator Cost Function Data of 330kV Nigerian Grid System

Bus No.	Station	α	β	γ	$P_G$min(MW)	$P_G$max(MW)
1	Egbin	12787.0	13.1	0.031	275.0	1100.0
2	Sapele	6929.0	7.84	0.13	137.5	550.0
3	Delta	525.74	-6.13	1.20	75.0	300.0
4	Afam	1998.0	56.0	0.092	135.0	540.0

Table 3: Line Data of 330kV Nigerian Grid System

To Bus	R	X	B		Rate A	Rate B	Rate C	Ratio	Angle	Status
25	1	0	0.00648	0	2000	2000	0.975	0.975	0	1;
26	2	0	0.01204	0	1000	1000	1000	1	0	1;
27	3	0	0.01333	0	1000	1000	1000	1	0	1;
28	4	0	0.01422	0	1000	1000	1000	0.95	0	1;
29	5	0	0.01638	0	1000	1000	1000	1.025	0	1;
30	6	0	0.01351	0	1000	1000	1000	0.95	0	1;
31	7	0	0.01932	0	1000	1000	1000	1	0	1;
10	8	0.0055	0.04139	1.885	1520	1520	1520	0	0	1;
11	8	0.00987	0.07419	0.8315	760	760	760	0	0	1;
8	15	0.00538	0.0405	0.4538	760	760	760	0	0	1;
21	8	0.00766	0.05764	0.646	760	760	760	0	0	1;
8	26	0.00098	0.00739	0.3313	1520	1520	1520	0	0	1;
8	27	0.00287	0.02158	0.2418	760	760	760	0	0	1;
9	11	0.00206	0.01547	1.56	2280	2280	2280	0	0	1;
9	29	0.0048	0.03606	1.6165	1520	1520	1520	0	0	1;
30	9	0.00159	0.01197	0.5366	1520	1520	1520	0	0	1;
31	9	0.00016	0.00118	0.053	1520	1520	1520	0	0	1;
11	10	0.01163	0.0875	0.9805	760	760	760	0	0	1;
10	22	0.00036	0.00266	0.119	1520	1520	1520	0	0	1;
24	10	0.00538	0.0405	0.454	1000	1000	1000	0	0	1;
10	25	0.00122	0.00916	0.4108	1520	1520	1520	0	0	1;
11	24	0.00412	0.03098	0.3472	760	760	760	0	0	1;
12	13	0.00774	0.05832	0.6526	760	760	760	0	0	1;
18	12	0.00904	0.06799	0.7619	760	760	760	0	0	1;

29	12	0.00189	0.01419	0.636	1520	1520	1520	0	0	1;
13	19	0.01042	0.07833	0.8778	760	760	760	0	0	1;
15	14	0.00605	0.04552	0.5101	760	760	760	0	0	1;
14	28	0.00049	0.00369	0.1656	1520	1520	1520	0	0	1;
15	17	0.00377	0.02838	0.318	760	760	760	0	0	1;
26	16	0.00248	0.01862	0.2087	760	760	760	0	0	1;
27	16	0.00102	0.00769	0.08613	760	760	760	0	0	1;
20	30	0.01218	0.09163	1.0269	760	760	760	0	0	1;
25	23	0.00028	0.00207	0.0928	1520	1520	1520	0	0	1;

Table 4: Bus Data of 330kV Nigerian Grid System

Bus	Type	Pd	Qd	Gs	Bs	Area	Vm	Va	BaseKV	Zone	Vmax	Vmin
1	3	0	0	0	0	1	1	0	16	1	1.1	0.9;
2	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
3	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
4	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
5	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
6	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
7	2	0	0	0	0	1	1	0	16	1	1.1	0.9;
8	1	156.8	79.9	0	0	1	1	0	330	1	1.1	0.9;
9	1	8.6	5.6	0	0	1	1	0	330	1	1.1	0.9;
10	1	429.9	258.4	0	0	1	1	0	330	1	1.1	0.9;
11	1	201	136.7	0	0	1	1	0	330	1	1.1	0.9;
12	1	166.2	97.8	0	0	1	1	0	330	1	1.1	0.9;
13	1	58.4	28.4	0	0	1	1	0	330	1	1.1	0.9;
14	1	144.7	88.4	0	0	1	1	0	330	1	1.1	0.9;
15	1	115.2	42	0	0	1	1	0	330	1	1.1	0.9;
16	1	82.1	44.5	0	0	1	1	0	330	1	1.1	0.9;
17	1	112.6	50	0	0	1	1	0	330	1	1.1	0.9;
18	1	184.9	60	0	0	1	1	0	330	1	1.1	0.9;
19	1	102.9	17.5	0	0	1	1	0	330	1	1.1	0.9;
20	1	60.3	70	0	0	1	1	0	330	1	1.1	0.9;
21	1	26.8	10.5	0	0	1	1	0	330	1	1.1	0.9;
22	1	292	114.9	0	0	1	1	0	330	1	1.1	0.9;
23	1	193.5	101.2	0	0	1	1	0	330	1	1.1	0.9;
24	1	139.4	61	0	0	1	1	0	330	1	1.1	0.9;
25	1	109.7	64.2	0	0	1	1	0	330	1	1.1	0.9;
26	1	0	0	0	0	1	1	0	330	1	1.1	0.9;
27	1	64.3	44.2	0	0	1	1	0	330	1	1.1	0.9;

Table 4: Bus Data of 330kV Nigerian Grid System

Bus	Type	Pd	Qd	Gs	Bs	Area	Vm	Va	BaseKV	Zone	Vmax	Vmin
28	1	119.3	65.7	0	0	1	1	0	330	1	1.1	0.9;
29	1	61.5	10.3	0	0	1	1	0	330	1	1.1	0.9;
30	1	0	0	0	0	1	1	0	330	1	1.1	0.9;
31	1	0	0	0	0	1	1	0	330	1	1.1	0.9;

IV. RESULTS AND DISCUSSION

Table 5 shows the optimal power schedule using MATPOWER to run OPF for Nigerian grid system for different loading scenarios. In this result four cases were compared with the base loading schedules. It can be deduced from the result that there is correlation between the load increment and losses and cost. Increasing the load by 30MW in Gombe, Ikeja, Benin and B/kebbi buses one after the other causes the losses as well as the fuel cost to increase

Table 5: OPF Schedule for Nigerian System for different loading Scenarios

Bus		Active Power Generated (MW)				
No.	**Name**	**Base Loading**	**Case 1 (Gombe)**	**Case 2 (Ikeja)**	**Case 3 (Benin)**	**Case 4 (B/Kebbi)**
1	Egbin	1063.91	1075.04	1075.01	1074.20	1074.05
2	Sapele	282.70	285.48	285.24	285.75	285.24
3	Delta	75.00	75.00	75.00	75.00	75.00
4	Afam	160.83	164.55	164.23	164.92	164.22
5	Shiroro	490.00	495.12	495.12	495.12	495.12
6	Kainji	350.00	353.66	353.66	353.66	353.66
7	Jebba	450.00	454.70	454.70	454.70	454.70
Total Generation		2872.44	2903.55	2902.96	2903.34	2901.99
Total Losses		42.34	43.45	42.86	43.24	41.89
Total Power Demand		2830.10	2860.10	2860.10	2860.10	2860.10
Total Cost in ₦/hr		**101,548.47**	**102,979**	**102,928.82**	**102,965.52**	**102,852.00**

V. CONCLUSION

In this paper, a power system simulation package referred to as MATPOWER is used extensively to study the Optimal Power Flow (OPF) of the Nigerian grid system. The real and reactive power generated by the seven generating stations of Nigerian network is scheduled without violation to any system constraints. The objective function values, the system losses and the optimal dispatch have been done using respective cost function of each thermal generator. During the simulation however, the fuel cost coefficient for the hydropower stations in Nigerian network are considered and set to zero and the thermal station real power limits on the other hand are manually set base on their power limits. This would serve as a demonstration for students and researchers intending to use the package and it envisioned to go a long way in assuring quality teaching and researches in power systems engineering field.

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