The West Africa Power Pool
Data Consultant Training Seminar

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The Economic Community of West African States (ECOWAS) and Purdue University, USA)

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MODEL I: Short Run, Power Trade Only

$$\min \sum_{t} \sum_{i} \sum_{z} c\overline{(i,z)} PG(i,z,t) + \overline{UEcost}\, UE(z,t) + \overline{UMcost}\, UM(z)$$

s.t.

(1) $$\sum_{i} PG(i,z,t) + \sum_{zp} PF(zp,z)\left(\overline{1\text{-}PFloss(zp,z)}\right) + UE(z,t) = \overline{D(z,t)} + \sum_{zp} PF(z,zp)$$

(2) $$PG(i,z,t) \le \overline{PGinit(i,z)}$$

(3) $$PF(z,zp) \le \overline{PFinit(z,zp)}$$

(4) $$\sum_{i} \frac{\overline{PGinit(i,z)}}{1+\overline{res(i,z)}} + UM(z) \ge \overline{D(z,peak)}$$

(5) $$\sum_{i} \overline{PGinit(i,z)} \ge A(z)\, D(z,peak)$$

where:

A) variables:

$PG(i,z,t)$ = power generation at i in z during t (MW)

$UE(z,t)$ = unmet energy demand in z during t (MW)

$UM(z)$ = unmet reserve requirement in z (MW)

$PF(zp,z)$ = power flow from zp to z (MW)

B) Parameters:

$\overline{c(i,z)}$ = cost/MW of generation at i in z ($)

$\overline{UEcost}, \overline{UMcost}$ = cost/MW of unmet demand/reserves ($)

$\overline{PFloss(zp,z)}$ = line loss from zp to z (%)

$\overline{D(z,t)}$ = demand in z during t (MW)

$\overline{PGinit(i,z)}, \overline{PFinit(zp,z)}$ = initial capacities (MW)

$\overline{res(i,z)}$ = reserve requirement for i in z (%)

$\overline{D(z,peak)}$ = peak demand in z (MW)

$A(z)$ = autonomy factor for z (%)

MODEL II: Short-Run, Power and Reserves Traded

$$\min \sum_{i} \sum_{z} \sum_{t} c\overline{(i,z)}\,PG(i,z,t) + \overline{UEcost}\,UE(z,t) + \overline{UMcost}\,UM(z)$$

s.t.

(1) $$\sum_{i} PG(i,z,t) + \sum_{zp} PF(zp,z)\left(\overline{1\text{-}PFloss(zp,z)}\right) + UE(z,t) = \overline{D(z,t)} + \sum_{zp} PF(z,zp)$$

(2) $$PG(i,z,t) \le \overline{PGinit(i,z)}$$

(3) $$PF(z,zp) \le \overline{PFinit(z,zp)}$$

(4) $$\sum_{i} \frac{\overline{PGinit(i,z)}}{1+\overline{res(i,z)}} + \sum_{zp} \frac{Fmax(zp,z)}{1+\overline{res(zp,z)}} + UM(z) \ge \overline{D(z,peak)} + \sum_{zp} Fmax(z,zp)$$

(5) $$\sum_{i} \overline{PGinit(i,z)} \ge \overline{A('z)} \ge \overline{D(z,peak)}$$

Where Fmax(zp,z) = reserves held by zp for z.

MODEL III: Long Run Model

$$\min \sum_{y=1}^{Y} \frac{\sum_{i}\sum_{z}\sum_{t} \overline{c(i,z)}\,PG(i,z,t,y) + \overline{UEcost}\,UE(z,t,y) + \overline{UMcost}\,UM(z,y)}{\left(1+\overline{disc}\right)^{y}} +$$

$$\sum_{y=1}^{Y}\sum_{\tau=y}^{Y} \frac{\overline{crf}\,\overline{expcost(i,z)}\,PGexp(i,z,y)}{\left(1+\overline{disc}\right)^{\tau}}$$

Subject to:

(1) & (3) With y added in variables

(2) $PG(i,z,t,y) \le \overline{PGinit(i,z)} - \sum_{\tau=1}^{y} PGexp(i,z,\tau)$

(4) $\sum_{i} \frac{\overline{PGinit(i,z)} + \sum_{\tau=1}^{y} PGexp(i,z,\tau)}{1+\overline{res(i,z)}} + \sum_{zp} Fmax(zp,z,y) + UM(z,y) \ge D(z,peak,y) + \sum_{zp} Fmax(z,zp,y)$

(5) $\sum_{i} \overline{PGinit(i,z)} + \sum_{\tau=1}^{y} PGexp(i,z,\tau) \ge A(z)\,D(z,peak,y)$

where:

New variables: $PGexp(i,z,y)$ = MW added in y at i in z

New parameters:

$\overline{\text{expcost}(i,z)}$ = cost/MW of expansion at i in z

$\overline{\text{disc}}$ = discount rate for present value purposes

$\overline{\text{crf}}$ = capital recovery factor

Implications of Model Structure on Data

1. The model is a <u>cash flow model</u>; cash outflows entered into the model in the year in which they take place.

2. No need to collect data on sunk costs (costs of past investments, etc.), only incremental costs.

3. Model assumes equipment purchases financed by borrowed money – hence equipment purchase cost shows up as an annualized cost, equal to the capital recovery factor times the Engineering, Procurement, and Construction (EPC) cost, in each year subsequent to the purchase date.

Cont.

4. Plant operating costs (fuel, variable O&M, water costs) should be average incremental costs for each plant, not marginal costs which might be lower due to say, take or pay fuel contracts. Ignore variable heat rates for existing thermal plants – assume heat rate at 100% load.

5. Plant equipment costs should be EPC costs, <u>not</u> including financing costs.

6. Fixed O&M ($/kW/yr) should be considered only for new plants; they are sunk costs for existing plants (unless plants mothballed).

Cont.

7. Reserve margins, autonomy factors, discount rate, crf, unserved energy and reserve costs are policy decisions; get them, if you can but don't spend a lot of time.

8. Line losses should be average incremental, not marginal.

9. Line capacities should be maximum transfer capability, not maximum capacity.

10. Generation capacities should be net effective (dependable) sent out capacity, not nameplate capacity.

11. Demands (D(z,t,y)) should be sent out demands, not received demands.