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OPTIMISATION OF 330KV NIGERIA ELECTRIC POWER SYSTEM BY PRIMAL-DUAL INTERIOR-POINT TECHNIQUE: IMPROVED PERFORMANCE ON SELECTED POWER STATIONS.

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ABSTRACT

The paper developed an optimization technique that is applied in 330 kV and other Extra High Voltage Networks. The Technique solves load flows which are non-linear with both equality and inequality constraints at the same time thereby saving time and saving the system from encountering problems due to delays in faults clearing. The existing solves one constraints after the other and has more than six (6) iterations before converging, while the developed method has few iterations and often converges after first iteration. The developed technique guarantees higher system power generation and consequently, larger loading with high system stability. With these advantages over the other methods the technique is realised by applying the non-negative Primal Variables ,"S" and "z" into the problem formulation to transform the Inequality constraint part to Equality constraints and subsequently apply another non-negative Dual Variables, "π" and "v" together with Lagrange multiplier "λ" to solve optimisation. Optimisation is solved by incorporating, Barrier Parameter "μ" which ensures feasible point(s) exist(s) within the feasible region (INTERIOR POINT), Damping Factor or Step length parameter "α", Step Size ΔY, in conjunction with Safety Factor "γ" (which improves convergence and keeps the non-negative variables strictly positive) are used for updating variables ($Y^1=Y^0+\alpha\Delta Y^0$). If initialised variables fail convergence test, iteration starts with the updated variables. The problem formulation is done economically through minimisation of cost of power generation; min $C(PG)= \alpha+\beta PG+\gamma PG^2$, $g(x)=0$, stands for conventional power flow equation and other

equality constraints, which is represented as; PG−PD−loss=0 and $\underline{h}$ £ h(x) £ $\hat{h}$, stands for operating limits on the system, which is represented as PGmin £ PG) £PGmax. The numerical algorithms of the method runs; Step Zero (Initialisation), Step One (Compute Newton Direction ΔY), Step Two (Update Variables), Step Three (Test for Convergence). Studies with results and analysis of improved performance by using PD-IP technique on the 330KV Bus of seven selected Power Stations namely; Shiroro, Afam, Geregu, Delta, Kainji and Jebba Power Stations of Nigeria where table 4 shows that percentage improvement to the existing methods. Therefore, this method ensures and guarantees high system stability.

INTRODUCTION

Though Fast Decoupled Load Flow (FDLF) (Vincovic and Mihalic, 2008) method was widely accepted by the industry because of its fast, simple to implement and with reduced computer storage requirements, several refinements were later made such as the Carpentiers Implicit Coupling (CrIC) modification, Carpenter J.L Active reactive decoupling for improved convergence characteristics of the reactive model (Zhang and Tolbert, 2007) and hybrid model (Gomez-Exposito et al, 2015).

The first known Interior-Point (I.P) method is usually attributed to Frisch, which is a logarithmic barrier method that was later in 1960s extensively studied by Fiacco and Mc Cormick to solve non-linear inequality constrained problems (Torren and Quintina, 2001, Granville, 2007). The greatest break-through in IP research took place in 1984, when Karmarka came up with a new IP method for Linear Programming LP reporting solution times of up to 50 times faster than the simplex method. Then Karmarka's algorithm is based on non-linear projective transformations. Later, several variants of Karmarka's IP method have been proposed and implemented.Finally, the Primal-Dual methods show that its algorithm (Shyamasundar, 2010) proved to perform better than earlier IP algorithms.

One of the drawbacks of IP methods is their difficulty in detecting infeasibility. The computational efforts of each iteration of an IP algorithm is dominated by the solution of large, sparce linear systems (Geletu et al, 2011). Therefore the performance of any IP code is highly dependent on the linear algebra kernel (Alamaniotis et al, 2012). Although in the last decade IP methods have achieved significant development, there are still many open questions that need more research to further improve their performance. This work addresses some of these issues (Qui and Deconinck, 2009).

Optimal load flow methods are essentially static optimisation procedures in which the optimal generation schedule that satisfies the load flow equations and minimises production cost C(X, U) is sought. The problem for a system of A interconnected areas may be stated as follows:

$$\text{Min } C(X, U) = \sum_{k=1}^{A} C_k (X_k, U_k)$$

Subject to the constraints that:

$$F(X, U, D^0) = 0$$

$$\underline{X} \leq X \leq \bar{X}$$

$$\underline{U} \leq U \leq \bar{U} \qquad (1.1)$$

Where X and U are vectors of control variables,

D^0 is constant introduced to facilitate solutions to the problems.

From the above equation, it is noted that basically three (3) constraints must be satisfied by X and U. The first is equality constraint that disallows any value of X and U that does not satisfy the load flow equations. The other two constraints are inequality constraints on X and U within the defined ranges.

A constrained minimisation problem like the above is solved by transforming it into an unconstrained minimisation problem. The merit of this new technique is; solving the above Load Flow problems faster, that is having faster algorithm (Xin-She and Xingshi, 2013) and in effect protect the 33OkV System from incessant blackouts(Capitanescu et al, 2012). As one of the shortcomings of the existing methods of load flow analysis (Momo et al, 2017) on 330kV power system is, time consumption as it has more than six iterations for one variable and this gives room for unwarranted blackouts and islanding conditions (Wu et al, 2010), as the existing methods solve equality and inequality constraints in Non-linear load flow problems separately, (Lui and Wu, 2017 and Yuan et al, 2016). Data collected from TCN, GenCos, DisCos (Odiah, 2011, Ebewele, 2014 and Awosope, 2003), from chapter 4 show that the existing methods have poor generation-assignment resulting in poor power generation and system stability.

OVERVIEW OF THE WORK

2.1 Optimisation Based On Economic Operation Of Power System

Consideration is made so that power system is operated as to supply all the (complex) loads (Moradi, et al 2011) at minimum cost (Wang and Murillo, 2007). Often total load is less than the available generation capacity (Fliscounakis et al, 2013) in developed world but not always so in Nigeria (Alawode and Jubril, 2010). Where the total load is less than, there are many possible generation assignment (Bakare et al, 2005 and Orike and Corne, 2013), but when there is peak load/demand for power, it means, all the available generation capacity is used resulting in no option. During options, (Capitanescu et al, 2011) power generation in system (PGi) is picked to minimise cost of production while satisfying load and the losses in the transmission system, min $C(PG) = \propto + \beta\ PGi + \gamma(PGi^2)$. Optimal economic dispatch (Yuan and Hesamzadel, 2017 and Xia and Elaiw, 2010) may require that all the power be imported from neighboring utility through a single transmission system (Street et al, 2014). Also, it is noted that, small variations in demand are taken care of by adjusting the generations already on line, while large variations_are accommodated basically by starting up generator units when the loads are on the upswing and shutting down when the loads decrease (Mao and Iravani, 2014). Although the problem is complicated by considering the long lead time required (6-8 hours) for preparing a “cold thermal unit for service”, (Colombo and Grothey, 2013). To avoid the cost of start-up or shut-down, there is a requirement that enough spare generation capacity (spinning reserve) (Arul et al, 2013) be available on-line in the event of a random generator failure (Awosope, 2003).

Mathematically, Economic Operation of Power System run thus,:-

$Fi\ (PGi) = PGi\ .\ Hi\ (PGi)$ also, $Fi\ (PGi) = a^i + b^i\ PGi + y^i\ PGi^2$ (2.1)

Cost, $Ci\ (PGi) = K.\ (PGi\ Hi\ (PGi)$ in (₦/hr), ie $K.\ (Fi\ (PGi)$ in (₦/hr) (2.2)

2.2. Optimisation Based On Mathematical Model Of Primal-Dual Interior-Point Technique

Min f(x)

Such that g(x) = 0 (2.3)

$\underline{h}$ £ h(x) £ $\hat{h}$

$x \in IR^n$ is a vector of decision variable with control/ non-functional dependent variable.

f: IR^n –IR is a scalar function standing for power system operation optimisation goal.

g: IR^n –IR^m is a vector function representing the conventional power flow equation and other equality constraints(Chiang and Grothey, 2014 and Chiang,2013).

h: IR^n –IR^p is a vector of functional variables with lower bound $\underline{h}$ and upper bound $\hat{h}$ representing the operating limits on the system.

It is assumed that f(x), g(x) and h(x) are twice continuously differentiable. Since the above problem minimises f(x) subject to h(x) $\geq$ 0. The objective is obtaining feasible point X. that attains the desired minimum.

III Methodology

3.1 Transforming Inequality Constraint To Equality

Transformation of (2.3) is done (Yang, et al 2016) by incorporating non- negative slack vectors ‘s’ and ‘z’ into the inequality constraint $\underline{h} \leq h(x) \leq \hat{h}$, imposing strict positivity conditions on those slacks (Yang, et al 2016) by incorporating them into logarithmic barrier terms (Babu and Harini, 2016):-

$$\left.\begin{array}{l} \text{Min } f(x) \\ \text{Subject to } g(x) = 0 \\ -s - z + \hat{h} - h = 0 \\ -h(x) - z + \hat{h} = 0 \\ \text{Into logarithmic barrier term as} \\ \text{Min } f(x) - \mu^k \sum_{i=0}^{p} (insi + inzi) \\ \text{Subject to } g(x) = 0 \\ -s - z + \hat{h} - h = 0 \\ -H(x) - z + \hat{h} = 0 \\ \text{“s”} \geq 0;\ \text{“z”} \geq 0 \end{array}\right\} \qquad \textbf{(3.1)}$$

Where, k is the iteration count or number and p the number of interconnected systems. Solving these equality constraints, ^we apply vectors of lagrangian multipliers called Dual-Variables “λ” “π” and “v” together with the Newton method. Where $\lambda \in IR^m$, $\pi \in IR^p$ and $v \in IR^{p.}$ The point “Y” becomes (s, z, π, v, x, λ) [Wu, et al 2012 and Ling, 2007) lagrangian function Lμ(y),

$$L\mu(y) = f(x) - \mu^k\ \Sigma(\text{in } si + \text{in } zi) - \lambda^T gx - \pi^T (s - z + h - \underline{h}) - V^T(-h(x) - z + h). \qquad \textbf{(3.2)}$$

3.3 Optimality Conditions

A local minimiser of (3.1) is expressed in terms of stationary point of Lx(y) satisfying the Karush-Kuhn Tucker (KKT) optimality conditions for the NLP (2.7)(Torren and Quintana, 2001 and Wu, et al 2012) as

$$zv \left\{ \begin{array}{l} s\ \pi \\ \quad \wedge \end{array} \right\}$$

$$\nabla y1(y) = \begin{matrix} s + z - \hat{h} + \underline{h} \\ h(x) + z - \hat{h} \\ \nabla x f(x) - Jg(x)^T \lambda + Jh(x)^T v \end{matrix} = 0 \qquad \textbf{(3.3)}$$

$- g(x)$

$\hat{V} = v + \pi$ for simplification

$$\begin{matrix} s\,\pi - m^k e \\ \nabla ylm(y) = \end{matrix} \left\{ \begin{matrix} zv - m^k e \\ s + z - \hat{h} + \underline{h} \\ h(x) + z - \hat{h} \\ \nabla x f(x) - Jg(x)^T \lambda + Jh(x)^T \hat{v} \\ - g(x) \end{matrix} \right\} = 0 \qquad \textbf{(3.4)}$$

Where L is local minimiser. Strict feasibility starting point is not mandatory for Primal Dual Interior Point technique but the condition (s, z)>0 and (p, v) >0 must be satisfied at every point in order to define the barrier term (Sivasubramani and Swarup, 2011 and Lage et al 2009). So, IP starts from a point y^0 that satisfies $(s^0, z^0)>0$ and $(p^o v^o) >0$. Primal Dual (IP) iterates (Capitanescu and Wehenkel, 2008) by one step of Newton method for NL equation to solve the KKT system (3.4). A step size is computed and variables updated, m^k values reduced. The algorithm terminates when the Primal and Dual infeasibilities and the complementary gap fall below pre-determined tolerance otherwise, with (s, z)>0 and (p, v) > 0 a new y^k is computed using one step of Newton method to find the roots of the NL functions applied to (3.3).

3.4 Estimating New Point (Y^K)

3.4.1 Computing Newton Direction or Step SizeΔY

The Newton direction is obtained by solving. Newton method (Tinney and Hart, 2007) with large sparse coefficient matrix (Geletu, et al 2011), with step size column matrix as shown below (Flicousnakis, et al 2013 and Molzahn, et al 2013):-

$$\left\{ \begin{matrix} p & 0 & s & 0 & 0 & 0 \\ 0 & \hat{v} & z & z & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & Jh & 0 \\ 0 & 0 & 0 & Jh^T & \nabla^2_x lm & -Jg^T \\ 0 & 0 & 0 & 0 & -Jg & 0 \end{matrix} \right\} \left\{ \begin{matrix} Ds \\ Dz \\ Dp \\ Dv \\ Dx \\ Dl \end{matrix} \right\} = \left\{ \begin{matrix} rs \\ rz \\ rp \\ rv \\ rx \\ rl \end{matrix} \right\} \qquad \textbf{(3.5)}$$

(Minot and Li, 2015 andMolzahn, et al 2013).

$$rs = \left\{ \begin{matrix} -sp + m^k e \\ rz = -z\hat{v} + m^k e \end{matrix} \right\}$$

$$\text{Where:}\quad \begin{aligned} rp &= -s - z + \hat{h} - \underline{h} \\ rv &= -h(x) - z + \hat{h} \\ rx &= -\nabla x\, f(x) + Jg(x)^T l - Jh(x)^T v \\ rl &= g(x) \end{aligned} \qquad \textbf{(3.6)}$$

Where, $\nabla^2_x lm$ is the combination of Hessians of objective and constraints functions.

$$\nabla^2_x lm(y) = \nabla^2_x f(x) - \nabla^2_x gj(x) lj + \nabla^2_x hj(x)\, vj \qquad (3.7)$$

Where "l" is local minimiser a function of differentiation, $\nabla^2_x f(x)$ is the Hessian or 2nd differentiation of objective function w.r.t.x, $\nabla^2_x g(x)$ is the Hessian or 2nd differentiation of equality constraint function w.r.t.x, ∇^2_x h (x) is the Hessian or 2nd differentiation of inequality constraint function w.r.t. x, $\nabla_x f(x)$ is the 1st differentiation of objective function w.r.t.x, Jg(x) is the 1st differentiation or Jacobian value of equality constraint w.r.t.x. Jh(x) is the 1st differentiation or Jacobian value of inequality constraint w.r.t.x.

Evaluation of the Newton directions is usually the computationally most expensive task in single iteration of PD-IP algorithm. In the computation of DY, factorisation of the coefficient matrix (3.5) is much more expensive than the forward and backward solutions that follow factorisation.

$$\boldsymbol{\Delta Y} = \left\{ \begin{matrix} Ds \\ Dz \\ Dp \\ Dv \\ Dx \\ Dl \end{matrix} \right\}$$

Where, **the scalars $\alpha^k{}_P$€ (0,1) and $\alpha^k{}_D$€ (0,1) are step length parameters** called **damping factors** which improve convergence and keep non-negative variables strictly positive, k is the iteration counts.

$$\left. \begin{aligned} a^k{}_P &= \min\,[1, \gamma \min\{-si^k/Dsi/Dsi<0,\ -zi^k/Dzi/Dzi<0\}] \\ a^k{}_D &= \min[1, \gamma \min\{-pi^k/Dpi/Dpi<0,\ -vi^k/Dvi/DVi<0\}] \end{aligned} \right\} \qquad \textbf{(3.8)}$$

The **scalar γ (0,1) is a safety factor** which ensures that the next point will satisfy the strict positivity conditions; typical constant values, γ^O = 0.25. γ^k = 0.99995.

3.4.3 Updating Variables

3.4.3.1Updating control variable(s) and primal variables

$X_1^k = X_1^{k-1} + a_p^k DX_1^{k-1}$ 2 control

$X_2^k = X_2^{k-1} + a_p^k\ DX_2^{k-1}$ variables

$S^k = S^{k-1} + a_p^k\ DS^{k-1}$ **(3.9)**

$Z^k = Z^{k-1} + a^k_p\ DZ^{k-1}$

3.4.3.2 Updating dual variables and lagrange multiplier

$p^k = p^{k-1} + a^k_D Dp^{k-1}$

$V^k = V^{k-1} + a^k_D V^{k-1}$

$l^k = l^{k-1} + a^k_D Dl^{k-1}$

3.5 Reducing the Barrier Parameter (μ^k)

The **scalar μ^k** is the **barrier parameter** or **complementary gap** (Lage, et al 2009) which ensures the feasible point X exist within the feasible region and it is obtained by

$\mu^{k+1} = W^k r^k$ **(3.10)**

Where Ω^k is chosen = max0.99W^{k-1}/2; 0.1) and it is called the **Centering Parameters**

With W^0 = (0.2 fixed) and μ^O = (0.1 fixed)

$r^k = (S^k)^T p^k + (Z^k)^T V^k$ **(3.11)**

μ^k is computed first, only if iteration (1) fails, then μ^1 and Y^1 is used to form iteration (2) as Y^0 and μ^0 (given) are used to form iteration (1)

3.6 Testing For Convergence

Interior-Point (IP) Iterations Are Considered Terminated Whenever

$V_1^k \leq \xi_1$, $m^k \leq \xi m$,

$V_2^k \leq \xi_1$, $\|\Delta X\|$:< ξ_2,

$V_3^k \leq \xi_2$, $\|g(X^k)\|$:< ξ_1,

$V_4^k \leq \xi_2$, $V_4^k \leq \xi_2$

is satisfied, where

V_1^k = max [max{h-h(x); h(x) – ĥ },$\|g(x)\|$¥],

$V_2^k = \frac{\|\nabla x f(x) - Jg(x)^T\lambda + Jh(x)^T V\|\infty}{1+\|x\|2+\|\lambda\|2+\|V\|2}$

Since$\|\lambda\|_2$ & $\|V\|_2$ are vectors of lagrangian multipliers,

they have no vector addition and so denominator reduces to $1 + \|x\|_2$ **(3.12)**

$V_3^k = \frac{\rho^k}{1+\|x\|2}$

$V_4{}^k = \frac{|f(x^k) - f(x^{k-1})|}{1 - |f(x^k)|}$

Typically, $\xi_1 = 10^{-4}$,

$\xi_2 = 10^{-2} E_1$ (i.e. 10^{-6}) ,

$\xi_x = 10^{-12}$.

Generally, $\xi_1 = 10^{-8}$ is chosen for quadratic functions with 2 variables.

If V^k_1, V^k_2 and V^k_3 are satisfied, then primal feasibility, scaled dual feasibility and complementary condition are satisfied which means that iterate K is a Karush Khun Turker (KKT) point of accuracy.

When numerical problems prevent verifying this condition, the algorithm stops as soon as feasibility of the equality constraint is achieved along with a very small fractional change in the objective value and negligible changes in the variables. The typical tolerances are **$\xi_1 = 10^{-4}$, $\xi_2 = 10^{-2}\ \xi_1$ and $\xi\mu = 10$** (Lavaei and Low, 2012)

3.7 Primal-Dual Interior-Point Technique Numerical Algorithms

Step 0: (Initialisation)

Set K = 0, define μ^0 and choose a starting point Y^0 that satisfies the strict positivity conditions.

Step 1: (Compute Newton Direction)

Form the Newton System at the current point and solve for the Newton Direction.

Step 2: (Update Variables)

Compute the step lengths in the Newton direction and update the primal and dual variables.

Step 3: (Test for Convergence)

If the new point satisfies the convergence criteria, stop. Otherwise, set K = K + 1, update the barrier parameter μ^k and return to step 1.

3.7.1 Representation of the Algorithms in Flow Chart (Xin-She andXingShi-He, 2013)

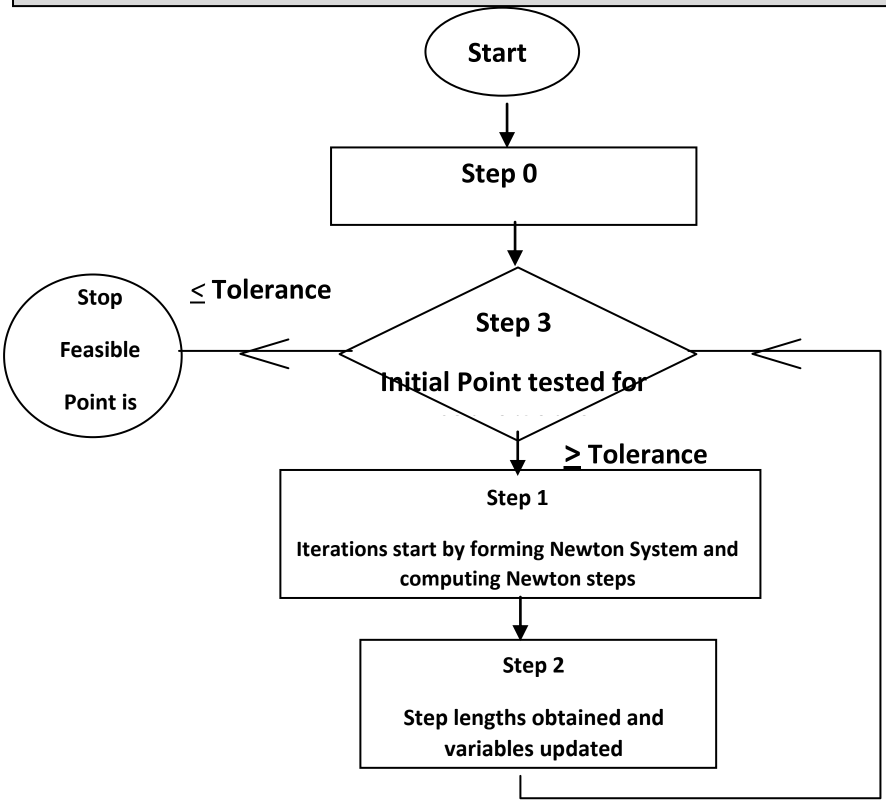

Fig. 3.1: PD-IP Technique's Flow Chart of Optimal Load Flow.

3.7.2 Implementation of the Algorithms of Primal-Dual Interior–Point Technique

3.7.2.1 Step Zero (0), Choosing an initial point

Although the starting point needs only to meet the strict positivity conditions (Cao, et al 2016), IP method performs better if some initial heuristics (Niu, et al 2014) are used, for instance, X^0 is middle point between the upper and the lower limits of the bounded variables.

3.7.2.1.1Initial point for one variable with linear inequality constraint, pick X^o a little less than $\hat{h}$. E.g $100 \leq X \leq 300$

Pick $X^0 = 250$

3.7.2.1.2 Initialising primal slack variables (S^0 and Z^0)

$$\left.\begin{array}{l} S^0 = \min[\max\{\gamma^o h^\Delta, h(X^0) - h\ min\}, (1-\gamma^0)\ h^\Delta] \\ S^0 = \min[\max\{0.25h^\Delta, h(X^0) - h\ min\}; 0.75h^\Delta] \\ \text{Where:} h^\Delta = h\ max - h\ min \\ \gamma^0 = 0.25 \\ 1 - \gamma^0 = 0.75 \end{array}\right\} \qquad (3.13)$$

$h(X^0)$ = values of X^0 including constant

$Z^0 = h^\Delta - S^0$

3.7.2.1.3 Initialising dual variables (π^0, V^0)

$$\left.\begin{aligned} p^0 &= m^0 (S^0)^{-1} e \quad \text{(e is diagonal I of matrix)} \\ p^0 &= 0.1(S^0)^{-1} \\ V^0 &= m^0 (Z^0)^{-1} e - p^0 \end{aligned}\right\} \qquad (3.14)$$

$l^0 = 0$ (since the power balance of steady state system is passive)

s^0

z^0

$$Y^o = \left\{\begin{matrix} p^0 \\ v^0 \\ x^0 \\ l^0 \end{matrix}\right\}$$

Convergence of the initial point is tested and if it fails then:

3.7.2.2 Step one (1), Computing Newton direction ΔY

With m^o defined and initial point Y^o obtained; Newton method (3.5), is formed and Newton direction computed with (3.6) and (3.7) of (3.5)

3.7.2.2.1 Newton direction for one variable with linear constraint

After iteration one, rs^o, rz^o, $rp^{0,}$ rv^o and $\nabla^2{}_x lm^0$ of (3.5) are zeros and convergence often occur.

From, row 6 of equation (3.5), where value of Dx^o is obtained. Dx value is substituted into row 4 to obtain Dz which in turn is substituted into row 3 where Ds = -Dz to obtain Ds. Ds value is substituted into row 1 to obtain Dp which in turn is substituted into row 2 to obtain Dv and finally Dv with Dx of row 6 are substituted into row 5 to obtain Dl.

3.7.2.3 Step two (2), Updating variables (Y^k) with step length parameter "α" (3.8). $Y^{1\,=}$ $Y^{O\,+}aDY^o$

Newton direction DY is computed from (3.5) and variables are updated from (3.9)

3.7.2.4 Step three (3), Testing for convergence If the new point satisfies the convergence criteria, stop.

IV Results And Analysis Of Improved Performance By Primal-Dual Interior-Point Technique

4.1 Data Collected And Used For The Research

From the relevant data collected between 2010 to October 2018 from formerly Power Holding Company of Nigeria PHCN and now, GenCos (Bamgboye, 2011), TransCos(TCN) and DisCos' logbooks, reports, visits to generating and transmission stations, line surveys and useful fault conditions and their solution from others(Mohammed, 2011 and Sambo, 2011) , interactions held with members of staff of the above companies and agencies(Oluseyi et al, 2007, Onohaebi and Lawal, 2010 and Odiah, 2011). Primal Dual interior –Point load flow technique (Alawode and Jubril, 2010) is applied to determine the best optimisation options (Ebewele, 2014) for quality, continuous and reliable services to Nigerian citizens (Orike and Corne, 2013 and Adebayo et al, 2012). Studies include installed capacities, available capacities and generated capacities of each generating station (Awosope, 2013 and Ebiojuomore, 2016) transmission line parameters, transformer ratings and loading, hourly readings of bus- voltages and daily peak load for the Networks (Awodiji et al, 2014, Anierobi et al, 2017 and Haruna et al, 2017). Obtaining load flow solution with conventional methods, then optimisation of the operations is done using PD-IP load flow technique (Ajenikoro and Olabode, 2016)

7.1.5 330 kV transmission system

Figure 7-2 below shows the 330 kV transmission system in 2020, under the assumption that all the ongoing and committed TCN, NIPP and certain JICA new projects will be completed by 2020.

The diagram shows the running generation and load in each DisCo area and the power flows between DisCos.

Dotted lines denote possible future projects beyond 2020.

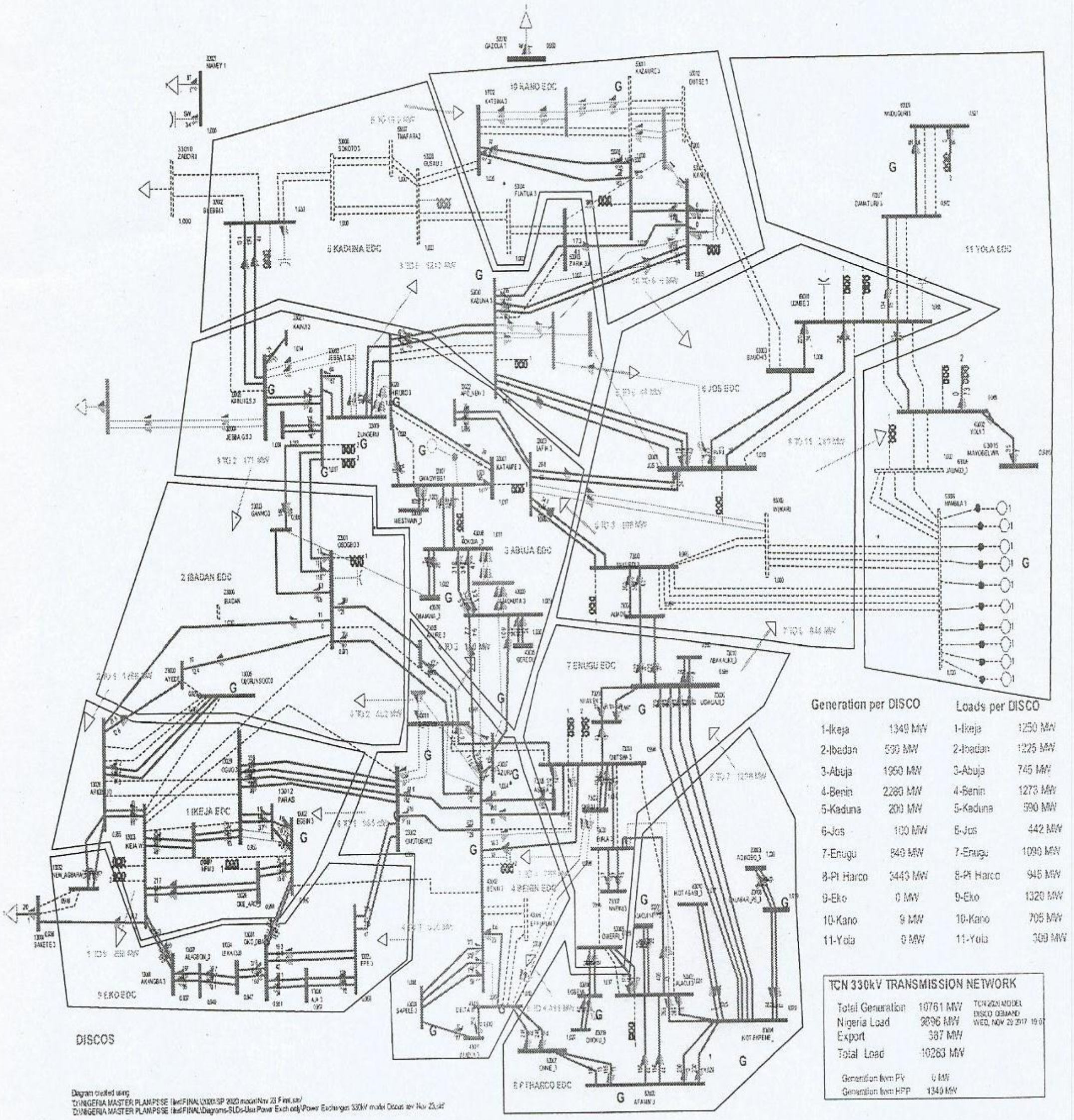

Fig. 4.1 330 kV transmission system 2020

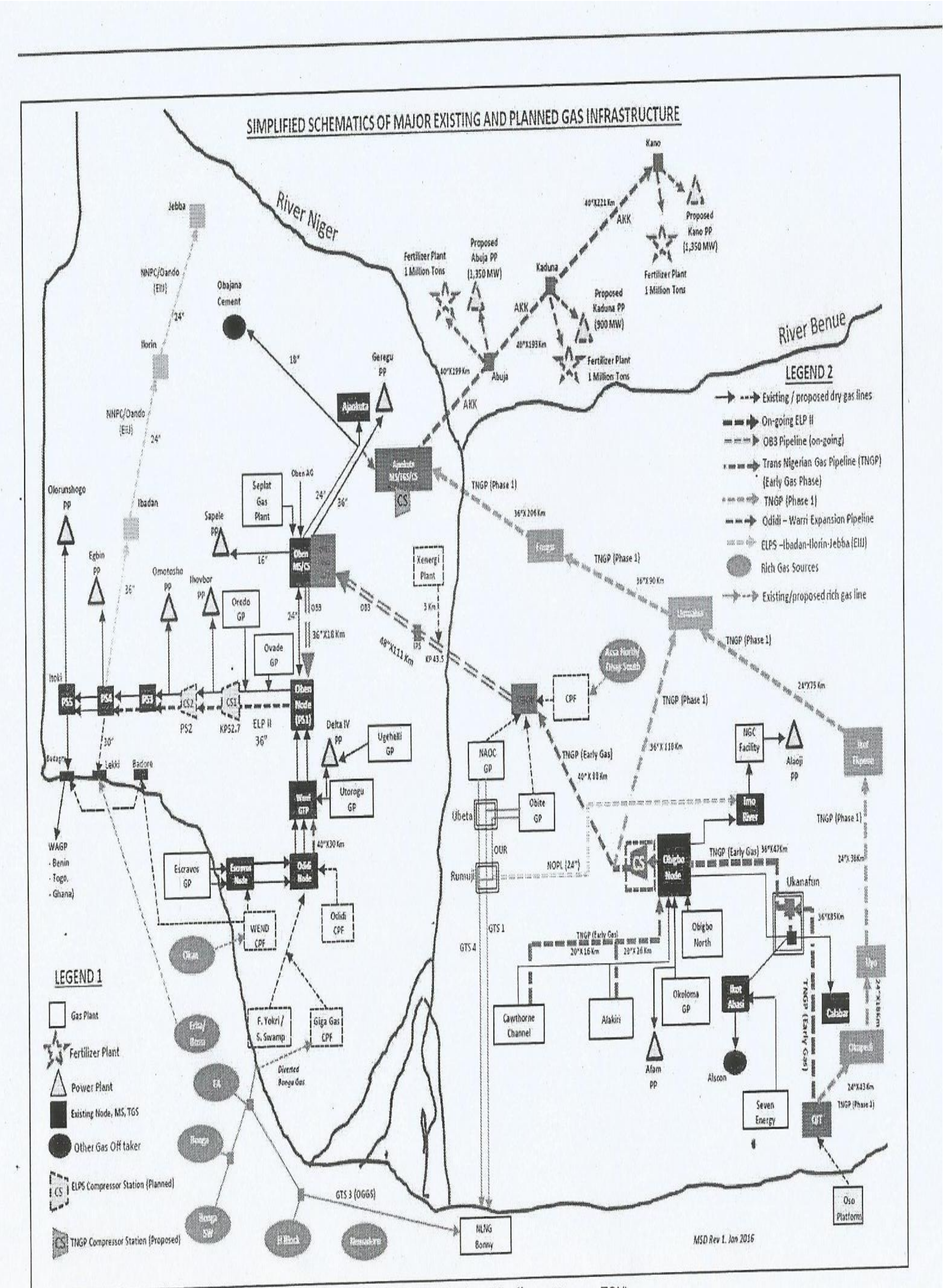

Fig. 4.2 Schematic with existing and proposed Gas Transmission Pipelines *(Source: TCN)*

Table 4.1: Generating Stations including National Independent Power Project Stations that are currently in operation in Nigeria as at 2017.

S/N	STATION	STATE	TURBINE	INSTALLED	AVAILABLE	GENERATION
1	Kainji	Niger	Hydro	760	298	259
2	Jebba	Niger	Hydro	504	404	352
3	Shiroro	Niger	Hydro	600	550	402
4	Egbin	Lagos	Steam	1320	1300	900
5*	Trans-Amadi	Rivers	Gas	210	100.00	57.3
6*	A.E.S (Egbin)	Lagos	Gas	250	250	211.8
7	Sapele	Delta	Gas	1020	200	170
8*	Ibom	Akwa-Ibom	Gas	155	55	25.3
9*	Okpai-(Agip)	Delta	Gas	900	400	221
10	Afam I-V	Rivers	Gas	726	100	60
11*	Afam VI (Shell)	Rivers	Gas	760	600	520
12	Delta	Delta	Gas	912	300	281
13	Geregu	Kogi	Gas	414	200	120
14*	Omoku	Rivers	Gas	150	100	53
15*	Omotosho	Ondo	Gas	304	150	88.3
16*	Olorunshogo (RollsRoyce) Phase 1	Ogun	Gas	500	500	450
17*	Olorunshogo phase II (Rolls Royce)	Ogun	Gas	230	200	150
Total power				9715	5707	4320.7

Table 4.2: 330kV Integrated Buses (Existing and NIPP) as at 2017.

S/N	BUSES	S/NO	BUSES	S/NO	BUSES
1	Shiroro	21	New heaven south	41	Yola
2	Afam	22	Makurdi	42	Gwagwalada
3	Ikot-Ekpene	23	B-kebbi	43	Sakete
4	Port-Harcourt	24	Kainji	44	Ikot-Abasi
5	Aiyede	25	Oshogbo	45	Jalingo
6	Ikeja west	26	Onitsha	46	Kaduna
7	Papalanto	27	Benin north	47	Jebba GS
8	Aja	28	Omotosho	48	Kano
9	Egbin PS	29	Eyaen	49	Katampe
10	Ajaokuta	30	Calabar	50	Okpai
11	Benin	31	Alagbon	51	Jebba
12	Geregu	32	Damaturu	52	AES
13	Lokoja	33	Gombe		
14	Akangba	34	Maiduguri		
15	Sapele	35	Egbema		
16	Abuja	36	Omoku		
17	Delta PS	37	Owerri		
18	Alaoji	38	Erunkan		
19	Aliade	39	Ganmo		
20	New haven	40	Jos		

Table 4.3: Basic description of 330kV Integrated Transmission line as at 2017.

Capacity of 330/132KV (MVA)	10,894
Number of 330KV substation	28
Total number of 330KV circuits	62
Length of 330KV lines (KM)	9,454.8
Number of control centres	4
Number of transmission lines	64
Numbers of buses	52
Number of generating stations	17

Table 4.4: Power Flows for the Integrated 330kV Network as at 2017.

S/N	Connected Bus		Sending End		Receiving End		Losses	
	From	To	P_{send} (pu)	Q_{send} (pu)	$P_{received}$ (pu)	$Q_{received}$ (pu)	Real power loss (pu)	Reactive power loss (pu)
1	49	1	0.1775	-0.0727	-0.1179	0.0734	0.0596	0.0007
2	14	6	-0.1939	-0.1200	0.1935	0.1201	0.0004	0.0001
3	2	18	-0.0556	-0.0383	0.0556	0.0384	0.0000	0.0001
4	2	3	0.0038	0.0017	-0.0039	-0.0018	-0.0001	-0.0001
5	2	4	-0.0063	0.0003	0.0066	-0.0003	-0.0003	0.0000
6	16	17	0.0512	-0.0566	-0.0516	0.0563	-0.0004	-0.0003
7	5	25	-0.1621	-0.099	0.1627	0.1005	0.0006	0.0015
8	5	6	-0.0186	-0.0119	0.0193	0.0121	0.0007	0.0002
9	5	7	-0.0283	-0.0182	0.0287	0.0188	0.0004	0.0006
10	8	9	-0.0999	-0.0619	0.9997	0.0624	-0.0002	0.0005
11	8	31	-0.0187	-0.0119	0.0185	0.0121	-0.0002	0.0002
12	10	11	-0.0215	-0.0134	0.0211	0.0136	-0.0004	0.0002
13	10	12	-0.0239	0.0166	0.0236	-0.0162	0.0003	0.0004
14	10	13	-0.0289	-0.0180	0.0291	0.0189	0.0002	0.0009
15	16	15	-0.1315	0.0163	0.1319	-0.0161	0.0004	0.0002
16	18	26	-0.2461	-0.01781	0.2463	0.1784	0.0002	0.0003
17	18	3	0.0457	0.0294	-0.0459	-0.0291	-0.0002	0.0003
18	18	37	-0.0153	-0.0116	0.0152	0.0117	-0.0001	0.0001
19	19	21	-0.0026	-0.0050	0.0029	0.0021	-0.0003	-0.0029
20	19	22	0.0031	0.0024	-0.0026	-0.0045	0.0005	-0.0021
21	23	24	-0.0885	-0.0543	0.0884	0.0548	-0.0001	0.0005
22	11	6	0.0159	0.0114	-0.0154	-0.0113	0.0005	0.0001
23	11	15	-0.0257	0.0595	0.0261	-0.0593	0.0004	0.0002
24	11	17	-0.0611	0.0549	0.0612	-0.0546	0.0001	0.0003
25	11	25	0.0108	0.0843	-0.0109	-0.0843	-0.0001	0.0000
26	11	26	0.0250	0.0194	-0.0255	-0.0190	0.0005	0.0004
27	11	27	0.0393	-0.0294	-0.0389	0.0300	0.0004	0.0006
28	11	9	0.0921	0.0779	-0.0925	-0.0779	-0.0004	0.0000
29	11	28	0.0476	0.0343	-0.0475	-0.0341	0.0001	0.0002
30	27	29	0.0308	0.0192	-0.0308	-0.0198	0.0000	-0.0006
31	30	3	0.0283	0.0182	-0.0286	-0.0182	0.0003	0.0000
32	32	33	0.0367	0.0240	-0.0364	-0.0239	-0.0003	0.0001
33	32	34	0.0485	0.0349	-0.0489	-0.0347	0.0004	0.0002

34	35	37	0.0181	0.0132	-0.0179	-0.0135	0.0002	-0.0003
35	35	36	0.0112	0.0088	-0.0111	-0.0089	0.0001	-0.0001
36	9	6	0.2148	0.1549	-0.2142	-0.1535	0.0006	0.0014
37	9	38	0.2605	0.1596	-0.2601	-0.1589	0.0004	0.0007
38	38	6	0.2601	0.1589	-0.2596	-0.1581	0.0005	0.0008
39	39	25	0.2668	-0.4055	-0.2636	0.4111	0.0032	0.0056
40	39	51	-0.2668	0.4055	0.2694	-0.4010	0.0026	0.0045
41	33	40	0.0674	0.1201	-0.0673	-0.1203	0.0001	-0.0002
42	33	41	0.0790	0.1002	-0.0789	-0.1003	0.0001	-0.0001
43	42	49	-0.0115	-0.0072	0.0118	0.0071	0.0003	-0.0001
44	42	13	0.0292	0.0181	-0.0289	-0.0182	0.0003	-0.0001
45	42	1	-0.0175	-0.0109	0.0177	0.0110	0.0002	0.0001
46	6	25	-0.0180	-0.0247	0.0181	0.0249	0.0001	0.0002
47	6	28	-0.0474	-0.0340	0.0475	0.0342	0.0001	0.0002
48	6	7	0.0283	-0.0185	-0.0283	0.0182	0.0000	-0.0003
49	6	43	0.0364	0.0202	-0.0366	-0.0205	-0.0002	-0.0003
50	44	3	0.0464	0.0332	-0.0461	-0.00332	0.0003	0.0000
51	3	21	0.0496	0.0316	-0.0494	-0.0310	0.0002	0.0006
52	45	41	0.0879	-0.1138	-0.0865	0.1149	0.0014	0.0011
53	51	25	0.2638	-0.3355	-0.2594	0.3448	0.0044	0.0093
54	47	51	-0.1669	0.6067	0.1674	-0.6055	0.0005	0.0012
55	51	24	-0.4846	0.0717	0.4877	-0.0653	0.0031	0.0064
56	51	1	-01733	-0.2580	0.1740	0.2644	0.0007	0.0064
57	40	46	-0.0029	-0.0054	0.0033	0.0060	0.0004	0.0006
58	40	22	-0.0027	-0.0050	0.0026	0.0055	-0.0001	0.0005
59	46	1	-0.1509	-0.1180	0.1512	0.1189	0.0003	0.0009
60	46	48	-0.1252	-0.0886	0.1244	0.0790	-0.0008	-0.0096
61	20	26	-0.1346	-0.0855	0.1351	0.0862	0.0005	0.0007
62	20	21	-0.0468	-0.0260	0.0466	0.0259	-0.0002	-0.0001
63	50	26	0.4219	-0.0682	-0.4177	0.0769	0.0042	0.0087
64	26	37	0.0156	0.0120	-0.0152	-0.0116	0.0004	0.0004
	Total Power loss						**0.0956**	**0.0754**

4.2 Improved Performance of Power Flow from Table 4.4 for Shiroro Power Station on Bus 1

Shiroro Power Station has available power (Wu et al, 2012) of capacity 550MW and generated power of capacity 402MW from table 4.1.Its Power contributions from table 4.4 on power flow are: from serial number 1, 0.1179p.u to Katamkpe of Bus 49, serial number 45, 0.0177p.u to Gwagwalada of Bus 42, serial number 56, 0.0870 to Jebba of Bus 51 and serial number 59, 0.1512p.u to Kaduna of Bus 46. The total power contribution is 0.1179+0.0177+0.0870+0.1512=0.3738p.u.

Generation is 0.4020p.u and loss is 0.4020-0.3738=0.0282p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Shiroro Power Station. Let the generated power (PG) based on available capacity of 0.5500p.u be 0.5000p.u and the power taken (PD) be 0.4800p.u heuristically (Wu et al, 2007). Let the maximum supply power $\hat{h}$ be 0.5500p.u and minimum supply power $\underline{h}$ be 0.4000p.u. Then the range h∆ is 0.1500p.u.

From problem formulation; Such as: g(PG); PG-0.4800-0.02(PG)=0, (Nagrath and Kothari, 2010)

h(PG); $0.4000 \leq h \leq 0.5500$.

Testing for convergence of control variable heuristically,

Pick,.g(PG); 0.5000-0.4800-(0.02x0.5000)=0.0100. $0.0100>10^{-4}$ (not converged).

Initialisation of Variables and Constants.PG^o=0.5000,(section3.7.2), PD^o=0.4800, h∆=0.1500, Primal and Dual variables, S^o=0.08, Z^o=0.07,π^o =1.0000, V^o=1.0000, V^o=2.0000, l^0 =0, (3.14)

Constants and Computational Constants.

μ^o=0.1 and Ω^o=0.2, (3.11), μ^k and Ω^k, (3.10), γ^0 = 0.25 but other γ^k = 0.9995 (3.8), $\varepsilon_1 = 10^{-4}$ (3.12).

Computations from Problem Formulation,

Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG)=0.007,

Step Size Δ Y is computed for from the large sparce coefficient matrix of (3.5). The right-end column (rY) called reference or set value of the (3.5) is computed for from (3.6),

Thus; rS^o=0, rZ^o=0, $r\pi^0$=0, rV^o=0, rPG^o=5.1035 and rl^0 =0.0100.

With only Δ Y as the only unknown in (3.5) the equation is solved and result obtained as; PG^o=-0.010204, Z^o=0.010204, S^o=-0.010204, $\Delta\pi$=0.010204, ΔV^o=-0.413262, Δl^0 =3.95610

Step Length Parameters (α), are Computed for, from (3.8).αP^o =1 and αD^o=0.6049.

Updating the Variables as Y^1,PG^1 = 0.5000 - 0.010204 =0.489796, S^1 = 0.1000 – 0.010204=0.089796,
Z^1 = 0.0500 + 0.010204=0.060204, π^1= 1.0000 + 0.6049x0.010204= 1.0062,
V^1 = 1.0000- (0.6049x0.413262) =0.75004, l^1 = 0 + 0.6049x3.95610 = 2.39304.

Testing for Convergence;
V_1^1; 0.489796–0.480000 – (0.02 x 0.489796) = 0. 0 <10^{-4} Convergence and Solution arrived and obtained.
Improved performance of PD-IP technique, on Shiroro Power Station with available power of 0.5500p.u, generates 0.4898p.u with 0.4800p.u demand, suffers only 0.0098p.u generation loss or 0.0700 availability loss as against the existing method that generates 0.4020p.u with 0.3738p.u demand, suffers 0.0282p.u generation loss or 0.1762p.u availability loss.

4.3 Improved Performance of Power Flow from Table 4.4 for Jebba Power Station on Bus 51

Jebba Power Station has available power of capacity 404MW or 0.404p.u and generated power of capacity 352MW or 0.352p.u from table 4.1.

Power contributions of Jebba Power Station from table 4.4 on power flows are; from serial number 40, 0.2694p.u to Ganmo of Bus 39, serial number 53, 0.2638p.u to Oshogbo of Bus 25, serial number 54, 0.0837p.u to Jebba GS of Bus 47, totaling 0.6169p.u. It takes from serial number 55, 0.2424p.u from Kainji of Bus 24 and from serial number 56, 0.0867p.u from Shiroro of Bus 1, totaling 0.3290p.u. Net power supplied by Jebba is 0.6169- 0.3290p.u = 0.2879p.u.Generation is 0.352p.u and loss is 0.352-0.2879=0.0641p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Jebba Power Station.

Let supply (PG) based on available capacity of 0.404p.u be 0.3800p.u and the power taken (PD) be 0.3700p.u heuristically. Let the maximum supply power $\hat{h}$ be 0.4040p.u and minimum supply power $\underline{h}$ be 0.3040p.u. Then the range hΔ is 0.1000p.u.

From problem formulation; Such as: g(PG); PG-0.3700-0.02(PG)=0, (Nagrath and Kothari, 2010) h(PG); 0.3040<h<0.4040.

Testing for convergence of control variable heuristically picked, g(PG); 0.3800-0.3700-(0.02x0.3800)=0.0024. 0.0024>10^{-4} (not converged).

Initialisation of Variables and Constants.

PG^o=0.3800,(section3.7.2), PD^o=0.3700, $h\Delta$=0.1000

Primal and Dual variables, S^o=0.075, Z^o=0.025, π^0 =1.3333, V^o=2.6667, V^0=4.0000, l^0 =0, (3.14).

Constants and Computational Constants.

μ^o=0.1 and Ω^o=0.2 (3.11), μ^k and Ω^k (3.10), γ^0 = 0.25 but other γ^k = 0.9995 (3.8), ε_1 =10^{-4} (3.12).

Computations from Problem Formulation,

Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG)=0.007,

Step Size ΔY is computed for from the large sparce coefficient matrix of (3.5) . The right-end column (rY) of the (3.5) is computed for from (3.6), Thus; rS^o=0, rZ^o=0, $r\pi^0$ =0, rV^o=0, rPG^o=-6.76933 and rl^0=0.0024.

With only ΔY as the only unknown in (3.5) the equation is solved and result obtained as;

ΔPG^o=-0.00245, ΔZ^o=0.00245, ΔS^o=-0.00245, $\Delta\pi^0$; =0.04355, ΔV^o=-0.43555, Δl^0=6.7630.

Step Length Parameters (α) are Computed for from (3.8). αP^o =1 and αD^o =1.

Updating the Variables as Y^1,

PG^1; 0.38000 - 0.00245 =0.37755, S^1; 0.07500 – 0.00245=0.07355, Z^1; 0.02500 + 0.00245=0.02745,

π^1; 1.33333 + 0.04355= 1.37688, V^1; 2.66667- 0.43555 =2.23112, l^1; 0+ 6.76300 = 6.76300.

Testing for Convergence,

V_1^1; 0.37755 – 0.37000 – (0.02 x 0.37755) = 0. 0 < 10^{-4} Convergence and Solution arrived and obtained.

Improved Performance of PD-IP technique, on Jebba Power Station with available power of 0.4040p.u generates 0.3776p.u with 0.3700p.u demand, suffers only 0.0076p.u generation loss or 0.0340p.u availability loss, as against the existing method that generates 0.352p.u with 0.2879p.u demand, suffers 0.0641p.u generation loss or 0.1161p.u availability loss.

4.4 Improved Performance of Power Flow from Table 4.4 for Sapele Power Station on Bus 15.

Sapele Power Station has available power of capacity 200MW or 0.200p.u and generated power of capacity 170MW or 0.170p.u from table 4.1.

Power contributions of Sapele Power Station from table 4.4 on power flows are; from serial number 15, 0.1319p.u to Aladja of Bus16, serial number 23, 0.0261 to Benin of Bus 11, the control center, totaling, 0.1580p.u. Generation is 0.1700p.u and loss is 0.1700-0.1580=0.0120p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Sapele Power Station

Let supply (PG) based on available capacity of 0.2000p.u be, 0.1750p.u. and the power taken (PD) be 0.1700p.u heuristically. Let the maximum supply power $\hat{h}$ be 0.2000p.u and minimum supply power $\underline{h}$ be 0.1000p.u. Then the range hΔ is 0.1000p.u.

From problem formulation

Such as: g(PG); PG-0.1700-0.02(PG)=0 (Nagrath and Kothari, 2010), h(PG); 0.1000<h<0.2000.

Testing for convergence of control variable heuristically, pick g(PG); 0.1750-0.1700-(0.02x0.1750)=0.0015. 0.0015>10^{-4} (not converged).

Initialisation of Variables and Constants.

PG^o=0.1750,(section3.7.2),. PD^o=0.1700, hΔ=0.1000,

Primal and Dual variables, S^o=0.075, Z^o=0.025, π^0=1.3333, V^o=2.6667, V^o=4.0000, l^0=0, (3.14).

Constants and Computational Constants.

μ^o=0.1 and Ω^o=0.2 (3.11), μ^k and Ω^k (3.10) , $\gamma^0 = 0.25$ but other $\gamma^k = 0.9995$ (3.8), $\varepsilon_1 = 10^{-4}$ (3.12).

Computations from Problem Formulation,

Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG)=0.007.

Step Size ΔY is computed for from the large sparce coefficient matrix of (3.5).The right-end column (rY) of the (3.5) is computed for from (3.6) Thus;$rS^{o}=0$, $rZ^{o}=0$, $r\pi^{0}=0$, $rV^{o}=0$, $rPG^{o}=-6.767925$ and $rl^{0}=0.0015$.

With only ΔY as the only unknown in (3.5) the equation is solved and result obtained as; $\Delta PG^{o}=-0.001531$, $\Delta Z^{o}=0.001531$, $\Delta S^{o}=-0.001531$, $\Delta\pi^{0}=0.027210$, ΔV^{o},= 0.27217, $\Delta l^{0}=6.633865$.

Step Length Parameters (α) are Computed for from (3.8). $\alpha P^{o}=1$ and $\alpha D^{o}=1$.
Updating the Variables as Y^{1},

PG^{1};0.175000-0.001531=0.173469, S^{1}; 0.07500–0.001531=0.073469, Z^{1}; 0.02500 + 0.001531=0.026531,

π^{1}; 1.33333 + 0.02721= 1.36054, V_1^{1}; 2.66667- 0.272170 =2.39450, l^{1} ; 0 + 6.633865 = 6.633865.

Testing for Convergence;
V_1^{1}; 0.173469 – 0.17000 – (0.02 x 0.173469) = 0. 0 < 10^{-4}Convergence and Solution arrived and obtained.
Improved Performance of PD-IP technique, on Sapele Power Station with available power of 0.2000p.u, generates 0.1735p.u with 0.1700p.u demand, suffers only 0.0035p.u generation loss or 0.0300p.u availability loss as against the existing method that generates 0.1700p.u with 0.1580p.u demand, suffers 0.0120p.u generation loss or 0.0420 availability loss.

4.5 Improved Performance of Power Flow from Table 4.4 for Afam Power Station on Bus 2

Afam Power Station has available power of capacity 100MW or 0.100p.u and generated power of capacity 60MW or 0.060p.u from table 4.1.

Power contribution of Afam Power Station from table 4.4 on power flows, is, from serial number 4, 0.0038p.u to Ikot Ekpene of Bus 3.
Generation is 0.0600p.u and loss is 0.0600-0.0038=0.0562p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Afam Power Station.

Let supply (PG) based on available capacity of 0.1000p.u be, 0.0900p.u and the power taken (PD) be 0.0850p.u heuristically.Let the maximum supply power $\hat{h}$ be 0.1000p.u and minimum supply power $\underline{h}$ be, 0.0500p.u. Then the range h∆ is 0.0500p.u.

From problem formulation;

Such as: g(PG); PG-0.08500-0.02(PG)=0 (Nagrath and Kothari, 2010), h(PG); 0.0500<h<0.1000.

Testing for convergence of the control variable, that is heuristically picked.

g(PG); 0.0900-0.0850-(0.02x0.0900)=0.0032. $0.0032>10^{-4}$ (not converged).

Initialisation of Variables and Constants.

PG^o=0.0900,(section3.7.2), pg29. PD^o=0.0850, h∆=0.0500,

Primal and Dual variables,

S^o=0.0375, Z^o=0.0125, π^0=2.6667, V^o=5.3333, $\overset{\triangle}{V}{}^o$=8.0000, l^0=0, (3.14) pg.30.

Constants and Computational Constants.

μ^o=0.1 and Ω^o=0.2, (3.11) , μ^k and Ω^k, (3.10), γ^0 = 0.25 but other γ^k = 0.9995 (3.8), ε =10^{-4} (3.12).

Computations from Problem Formulation,

Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG) =0.007,

Step Size ∆Y is computed for from the large sparce coefficient matrix of (3.5). The right-end column (rY) of the (3.5) is computed for from (3.6), Thus; rS^o=0, rZ^o=0, $r\pi^0$=0, rV^o= -0.0025, rPG^o= -9.43396 and rl^0=0.0032.

With only ∆Y as the only unknown in (3.5) the equation is solved and result obtained as;

ΔPG^o=-0.00327, ΔZ^o=0.000765, ΔS^o=-0.000765, $\Delta\pi^0$ =0.05440, ΔV^o=-0.5440, Δl^0=9.0714.

Step Length Parameters (α) are Computed for from (3.8). αP^o=1 and αD^o =1.

Updating the Variables as Y^1,

PG^1;0.090000-0.003270=0.086730, S^1;0.037500–0.000765=0.036735,

Z^1;0.012500+0.000765=0.011735,

π^1; 2.66667 + 0.05440= 2.7207, V^1; 5.3333- 0.5440 =5.8773, l^1; 0 + 9.0714= 9.0714.

Testing for Convergence;
V_1^1; 0.086730–0.085000 – (0.02 x 0.086730) = 0. 0 < 10^{-4}Convergence and Solution arrived and obtained.

Improved Performance of PD-IP technique, on Afam Power Station with available power of 0.1000p.u generates 0.08673p.u with 0.08500p.u demand, suffers only 0.00173p.u generation loss or 0.0150p.u availability loss as against the existing method that generates 0.0600p.u with 0.0038p.u demand, suffers 0.0562p.u generation loss or 0.0962p.u availability loss.

4.6 Improved Performance of Power Flow from Table 4.4 for Kainji Power Station on Bus 24

Kainji Power Station has available power of capacity 298MW or 0.2980p.u and generated power of capacity 259MW or 0.2590p.u from table 4.1.
Power contribution of Kainji Power Station from table 4.4 on power flows is from serial number 23, 0.0884p.u to Birnin Kebbi of Bus 23. Generation is 0.2590p.u and loss is 0.2590 - 0.0884=0.1706p.u.

Optimisati\On Based on Primal-Dual Interior-Point Technique on Kainji Power Station.

Let supply (PG) based on available capacity of 0.2980p.u be 0.2800p.u and the power taken (PD) be 0.2700p.u heuristically. Let the maximum supply power $\hat{h}$ be 0.2980p.u and minimum supply power $\underline{h}$ be 0.1980p.u. Then the range h∆ is 0.1000p.u.

From problem formulation;
Such as: g(PG); PG-0.2700-0.02(PG)=0, (Nagrath and Kothari, 2010), h(PG); 0.1980<h<0.2980.
Testing for convergence of control variable, heuristically picked, g(PG); 0.2800-0.2700-(0.02x0.2800)=0.0044. 0.0044>10^{-4} (not converged).

Initialisation of Variables and Constants.
PG^o=0.2800,(section3.7.2), pg29. PD^o=0.2700, h∆=0.1000,
Primal and Dual variables,S^o=0.075, Z^o=0.025, π^0=1.3333, V^o=2.6667, V^o=4.0000, l^0=0, (3.14).

Constants and Computational Constants.
μ^o=0.1 and Ω^o=0.2 (3.11), μ^k and Ω^k (3.10), γ^0 = 0.25 but other γ^k = 0.9995 (3.8), ε_1 =10^{-4} (3.12).

Computations from Problem Formulation,
Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG)=0.007.

Step Size ΔY is computed for from the large sparce coefficient matrix of (3.5). The right-end column (rY) of the (3.5) is computed for from (3.6), Thus; rS^o=0, rZ^o=0, r π^0r=0, rV^o= -0.007, rPG^o= -6.76863 and rl^0=0.0044.

With only ΔY as the only unknown in (3.5) the equation is solved and result obtained as; ΔPG^o=-0.00449, ΔZ^o= -0.00251, ΔS^o= +0.00251, $\Delta\pi^o$ = -0.04462, ΔV^o= 0.44640, $\Delta\ l^0$= 7.36226.

Step Length Parameters (α) are Computed for from (3.8). αP^o =1 and αD^o =1.

Updating the Variables as Y^1,
PG^1; 0.28000 - 0.00449 =0.27551, S^1; 0.07500 + 0.00251 = 0.07751, Z^1; 0.02500 - 0.00251=0.02249,
π^1; 1.33333 - 0.04462= 1.28871, V^1; 2.6667+ 0.4464 =2.2203, l^1; 0 + 7.36226 = 7.36226.

Testing for Convergence;
V_1^1; 0.27551 – 0.27000 – (0.02 x 0.27551) = 0. 0 < 10^{-4}Convergence and Solution arrived and obtained.

Improved Performance of PD-IP technique, on kainji Power Station with available power of 0.2980p.u generates 0.2755p.u and 0.2700p.u demand, suffers only 0.0055p.u generation loss or 0.0280p.u availability loss, as against the existing method that generates 0.2590p.u with 0.0884p.u demand, suffers 0.1706p.u generation loss or 0.2096p.u availability loss.

4.7 Improved Performance of Power Flow from Table 4.4 for Geregu Power Station on Bus 12

Geregu Power Station has available power of capacity 200MW or 0.2000p.u and generated power of capacity 120MW or 0.1200p.u from table 4.1.

Power contribution of Geregu Power Station from table 4.4 on power flows is, from serial number 13, 0.0236p.u to Ajaokuta of Bus 10. Generation is 0.1200p.u and loss is 0.1200 - 0.0236=0.0964p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Geregu Power Station.

Let supply (PG) based on available capacity of 0.2000p.u be 0.1800p.u and the power taken (PD) be 0.1750p.u heuristically.Let the maximum supply power $\hat{h}$ be 0.2000p.u and minimum supply power $\underline{h}$ be 0.1000p.u. Then the range $h\Delta$ is 0.1000p.u.

From problem formulation;

Such as: g(PG); PG-0.1750-0.02(PG)=0 (Nagrath and Kothari, 2010), h(PG); $0.1000<h<0.2000$.

Testing for convergence of control variable heuristically picked. g(PG); 0.1800-0.1750-(0.02x0.1800)=0.0014. $0.0014>10^{-4}$ (not converged).

Initialisation of Variables and Constants.

$PG^o=0.1800$,(section3.7.2), pg.29. $PD^o=0.1750$, $h\Delta=0.1000$,

Primal and Dual variables, $S^o=0.075$, $Z^o=0.025$, $\pi^0=1.3333$, $V^o=2.6667$, $V^o=4.0000$, $l^0=0$, (3.14).

Constants and Computational Constants.

$\mu^o=0.1$ and $\Omega^o=0.2$ (3.11), μ^k and Ω^k (3.10), $\gamma^0 = 0.25$ but other $\gamma^k = 0.9995$ (3.8), $\varepsilon_1 = 10^{-4}$ (3.12).

Computations from Problem Formulation,

$Jg(PG)=0.98$, $J^2g(PG)=0$, $Jh(PG)=1$, $J^2h(PG)=0$, $\nabla^1C(PG)=4.1+0.007PG$ and $\nabla^2C(PG)=0.007$, Step Size ΔY is computed for from the large sparce coefficient matrix of (3.5). The right-end column (rY) of the (3.5) is computed for from (3.6) Thus; $rS^o=0$, $rZ^o=0$, $r\pi^0=0$, $rV^o= -0.005$, $rPG^o= -6.76793$ and $rl^0=0.0014$.

With only ΔY as the only unknown in (3.5) the equation is solved and result obtained as; $\Delta PG^o=-0.001429$, $\Delta Z^o= -0.003571$, $\Delta S^o= +0.003571$, $\Delta\pi^0 = -0.063483$, $\Delta V^o = 0.63484$, $\Delta l^0= 7.55384$

Step Length Parameters (α) are Computed for from (3.8). $\alpha P^o =1$ and $\alpha D^o =1$.
Updating the Variables as Y^1,

PG^1;0.18000-0.0014249=0.178571, S^1;0.07500+0.003571=0.078571, Z^1; 0.02500 - 0.003571=0.021429,
π^1; 1.33333 - 0.063483= 1.269850, V^1; 2.6667+ 6.3484 =2.03183, l^1 ; 0 + 7.55384 = 7.55384.
Testing for Convergence;

V_1^1; 0.178571–0.175000– (0.02 x 0.178571)=0. $0 < 10^{-4}$ Convergence and Solution arrived and obtained.
Improved Performance of PD-IP technique, on Geregu Power Station with available power of 0.2000p.u generates 0.17857p.u with 0.17500p.u demand, suffers only 0.00357p.u generation loss or 0.02500p.u availability loss, as against the existing method that generates 0.1200p.u with 0.0236p.u demand, suffers 0.0964p.u generation loss or 0.1764p.u availability loss.

4.8 Improved Performance of Power Flow from Table 4.4 for Delta Power Station on Bus 17

Delta Power Station has available power of capacity 300MW or 0.3000p.u and generated power of capacity 281MW or 0.2810p.u from table 4.1.
Power contributions of Delta Power Station from table 4.4 on power flows are; from serial number 6, 0.0516p.u to Aladja of Bus 16, serial number 24, 0.0612p.u to Benin of Bus 11. It supplies total of 0.1128p.u. Generation is 0.2810p.u and loss is 0.2810 - 0.1128=0.1082p.u.

Optimisation Based on Primal-Dual Interior-Point Technique on Delta Power Station.

Let supply (PG) based on available capacity of 0.3000p.u be 0.2850p.u and the power taken (PD) be 0.2750p.u heuristically, Let the maximum supply power $\hat{h}$ be 0.3000p.u and minimum supply power $\underline{h}$ be 0.2000p.u. Then the range hΔ is 0.1000p.u.

From problem formulation;

Such as: g(PG); PG-0.2750-0.02(PG)=0 (Nagrath and Kothari, 2010), h(PG); $0.2000<h<0.3000$.

Testing for convergence of control variable heuristically picked.

g(PG); 0.2850-0.2750-(0.02x0.2850)=0.0043. $0.0043>10^{-4}$ (not converged).

Initialisation of Variables and Constants.

PG^o=0.2850,(section3.7.2), pg29. PD^o=0.2750, hΔ=0.1000,

Primal and Dual variables,S^o=0.075, Z^o=0.025, π^0=1.3333, V^o=2.6667, V^o=4.0000, l^0=0, (3.14).

Constants and Computational Constants.

μ^o=0.1 and Ω^o=0.2 (3.11), μ^k and Ω^k (3.10), $\gamma^0 = 0.25$ but other $\gamma^k = 0.9995$ (3.8), $\varepsilon_1 = 10^{-4}$ (3.12).

Computations from Problem Formulation,

Jg(PG)=0.98, J^2g(PG)=0, Jh(PG)=1, J^2h(PG)=0, ∇^1C(PG)=4.1+0.007PG and ∇^2C(PG)=0.007,

Step Size ΔY is computed for from the large sparce coefficient matrix of (3.5). The right-end column (rY) of the (3.5) is computed for from (3.6),Thus; rS^o=0, rZ^o=0, $r\pi^o$=0, rV^o= -0.005, rPG^o= -4.768662 and rl^0=0.0043

With only ΔY as the only unknown in (3.5) the equation is solved and result obtained as;

ΔPG^o=-0.0043878, ΔZ^o=-0.0056122, ΔS^o=+0.0056122, $\Delta\pi^0$= -0.099773, ΔV^o = 0.997712, Δl^0= 5.884024.

Step Length Parameters (α) are Computed for from (3.8). αP^o =1 and αD^o =1.

Updating the Variables as Y^1,

PG^1;0.285000-0.004378=0.2806122, S^1;0.0750000+0.0056122=0.0806122, Z^1;0.0250000-0.0056122=0.0206122, π^1; 1.33333-0.06667=1.26666, V^1; 2.66667+0.66667=3.33334, l^1 ; 0+5.88404 = 5.88404.

Testing for Convergence;

V_1^1; 0.2806122–0.275000–(0.02 x 0.2806122)=0. 0<10^{-4} Convergence and Solution arrived and obtained.

Improve Performance of PD-IP technique, on Delta Power Station with available power of 0.3000p.u generates 0.2806p.u and supplies 0.2750p.u, suffers only 0.0056p.u generating loss or 0.0250 availability loss, as against the existing method that generates 0.2810p.u with 0.1128p.u demand, suffers 0.1082p.u generation loss or 0.1872p.u availability loss.

Table 4.7 Summary of Optimisation of Load Flow Problems By Primal-Dual Interior-Point Technique over the Existing Methods (Values in P.U.).

Bus		**Number of Iterations**		**Power Generation**			**Power Demand**			**Power Loss**		
Name	**No.**	**PD-IP Tech**	**Existing**	**PD-IP Tech**	**Exist-Ing**	**% Improvment**	**PD-IP Tech**	**Exist-ing**	**% Impro Vment**	**PD-IP Tech**	**Exist Ing**	**% Improvement**
Shiroro	1	1	≥6	0.490	0.402	22	0.480	0.374	15	0.010	0.028	64
Afam	2	1	≥6	0.087	0.060	28	0.085	0.004	2050	0.002	0.056	96
Geregu	12	1	≥6	0.179	0.120	48	0.175	0.024	625	0.004	0.096	96
Sapele	15	1	≥6	**0.174**	0.170	02	0.170	0.158	08	0.004	0.012	67
Delta	17	1	≥6	0.281	0.281	00	0.275	0.113	142	0.006	0.108	94
Kainji	24	1	≥6	0.276	0.259	07	0.270	0.088	213	0.006	0.171	96
Jebba	51	1	≥6	0.378	0.352	08	0.370	0.288	30	0.008	0.064	88

Note: The Seven Power Stations' buses are chosen for analysis as a special case of 52 bus system as they contributed to the bulk supply of power to the system.

5.1 DISCUSSION OF RESULTS

Generally, the work reveals that Primal-Dual IP load flow technique optimisation excels others as it solves one variable with linear constraints function of equality and inequality and obtains solutions at a very fast rate as it converges often at first iteration. It results in much improved larger power dispatch and consumption from system, thereby saving the system from unnecessary outages and blackouts.

Note: The Seven Power Stations' buses are chosen for analysis as a special case of 52 bus system as they contributed to the bulk supply of power to the system.

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