A Comparative Application of Shunt Capacitor and Load Tap – Changing Transformer (LTCT) tothe Optimal Economic Dispatch of Generation on Nigerian 330kV, 24-Bus Grid System

Olakunle Elijah Olabode, Oluremi Adufe Arowolo, Muyiwa Paul Arowolo

Abstract-- This paper presentsa Comparative Application of Shunt Capacitor and Load Tap – Changing Transformer (LTCT) tothe Optimal Economic Dispatch of Generation on Nigerian 330kV, 24-Bus GridSystem. The Nigerian 330kV grid was optimized with Shunt Capacitor and Load Tap –Changing Transformer, a comparison was made at optimal dispatch of generation.In this work, the Newton Raphson iterative algorithm was adopted due to its quadratic convergence after a few iterations. A Sub-MATLAB based program was also used to evaluate transmission loss B –coefficients and the optimal dispatch generation for each generating unit. The results of the analysis showed that with the system reinforced with LTCT, the total cost of generation and the system transmission losses reduced by 0.97% and 4.02% respectively while the percentage reduction observed with the system reinforced with Shunt Capacitor are 0.83% and 3.3% respectively. A significant improvement occurred where voltage magnitude fall below the minimum acceptable range with the system reinforced with Shunt Capacitor and LTCT. In all LTCT gives better result than Shunt Capacitor in term of reduction in total cost of generation, total system losses and voltage profile enhancement.

Index Terms: Economic Load Dispatch (ELD), Load Tap-Changing Transformer (LTCT), Optimal Dispatch of Generation,Power Flow, Shunt Capacitor

◆

1.0 INTRODUCTION

The geometrical increase in complexity of interconnections coupled with the size of the areas of electrical power systems that are being controlled in a coordinated way necessitate economic load dispatch which aimed at finding the optimum generation among the existing units so that the total cost of generation is minimized. The cost associated with the power generation is exorbitant hence optimum dispatch saves a substantial amount of moneywhile simultaneously satisfying the power balance equations and various other constraints in the system [1].

Economic load dispatch (ELD) allocates power generations to match load demand at minimal possible cost without violating power units and system constraints [2].

The Economic Load Dispatch is an optimization problem which could either be convex and non-convex. In a convex ELD problems,the fuel-cost curves of the generating units are piece-wise linear and increases monotonically while an ELD problems that take into consideration ramp rate limits, prohibited operating zones, emission,valve point effects, line flow limits, spinning reserve requirementand multi-fuel options is regarded as non-convex [3].Convex ELD optimization problemmodelled power balance equation and generators with smooth quadratic cost functions while a sine function coupled with smooth quadratic function is used to model a non-convex ELD optimization

---

- *Olakunle Elijah Olabode is*currently rounding off his *M.Tech Degree in Electrical & Electronics Engineering* (Power & Machine),*Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria*. Email: 095082@gmail.com
- *Oluremi Adufe Arowolo is a senior lecturer in the Department of Computer Science, Tai Solarin College of Education, Omu-Ijebu, Ogun State, Nigeria and currently pursuing her PhD in Computer Science& Engineering inLadoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria. Email:oluodedeji@ yahoo.com*
- *Muyiwa Paul Arowolo works withMainstream Energy Solution Limited, Jebba North, Niger State and currently finishing* his M.Tech *Degree in Electrical& Electronics Engineering (Power & Machine),Ladoke Akintola University of Technology, P.M.B 4000, Ogbomoso, Oyo State, Nigeria.*

problems[3], hence non-convex ELD optimization problem is a complete and practical model of ELD.

The solution methodologies for convex ELD optimization problem includeslambda iteration, base point, participation method,linear programming, quadratic programming,gradient and Newton's methods [4-6], with these conventional/ classical methods treatment of operational constraints are difficult and complex when they applied to non-convex ELD problems hence heuristic search methods such as simulated annealing(SA), genetic algorithm (GA), particle swarm optimization(PSO), evolutionary programming (EP), biogeography based optimization (BBO), chaotic ant swarm optimization (CASO) and firefly algorithm (FA) are employed to solve non-convex ELD problems[7-10].

In this paper, the researchers carried out a comparative application of Shunt Capacitor and Load Tap-Changing Transformer (LTCT) to Nigerian grid system taking into consideration its effect on the cost of generation and the transmission losses. The test case system used is Nigerian grid which is essentially a 24-bus, 330kV network interconnecting four thermal generating stations (Sapele, Delta, Afam and Egbin) and three hydro stations (Kainji, Jebba and Shiroro) to various load points on the grid. The operating cost of hydro units insignificantly changes with the output and as a result, it sometimes assumed to be negligible in most cases, in line with this foregoing, it was taken as zeroes in this paper work. Also, thermal plants operating cost change significantly with the output power level since the total operating of a power plant is a function of fuel cost, cost of labour, supplies and maintenance [11, 12].

2.0 NEWTON-RAPHSON ITERATIVE ALGORITHM FOR POWER FLOW SOLUTIONS

The solution to non-linear algebraic equations are usually achieved with the aid of iterative techniques and since power system equations are mostly nonlinear algebraic equations they therefore require iterative algorithms to solve them. Newton-Raphson iterative technique is mostly preferred to other iterative techniques due to its inherent advantage such least no of iterations, faster quadratic convergences, comparatively good reliability and the number of non-linear algebraic equations to be solved is reduced to$2n-1$[9, 13]. Newton-Raphson techniques approximate a set of non-linear simultaneous equations to a set of linear simultaneous equations employing Taylor's series expansion while limiting the terms to the first approximation [13]. The power injected at bus i^{th} in a typical power system is given by;

$$P_i - jQ_i = V_i^* I_i = V_i^* \sum_{i=1}^{n} Y_{ik} V_k \qquad (1)$$

Separating the real and imaginary part of equation (1) after substituting for bus voltage an expressing in rectangular coordinate we have equation (2) and (3) as given below;

$$P_i = e_i(e_i G_{ii} + f_i B_{ii}) + f_i(f_i B_{ii} - e_i B_{ii}) + \sum_{k=1,k\neq i}^{n} [e_i(e_k G_{ik} + fkBik + fifk\, Gik - ek\, Bik \qquad (2)$$

$$Q_i = f_i(e_i G_{ii} + f_i B_{ii}) - e_i(f_i B_{ii} - e_i B_{ii}) - j \sum_{k=1,k\neq i}^{n} [f_i(e_k G_{ik} + fkBik - eifk\, Gik - ek\, Bik \qquad (3)$$

Where;$V_i = e_i + jf_i, V_k = e_k + jf_k, Y_{ik} = G_{ik} - j\,B_{ik},\ e_i$ and f_i, represent real and imaginary part of $V_i, e_k\ and\ f_k$ represent real and imaginary part V_k while G_{ik} and B_{ik} are the conductance and susceptance respectively.

Newton-Raphson method transforms a set of the nonlinear equations to linear equations by the iteration. For simplicity, the above equations (2) and (3) can be written in simple compact matrix form as defined below;

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta \upsilon \end{bmatrix} \qquad (4)$$

Where mismatch vector is$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$, the correction vector is $\begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix}$, ΔP and ΔQ are bus active and reactive power mismatches, $\Delta V$and $\Delta \delta$ represent bus voltage angle and magnitude vectors in an incremental form while $J_1\ to\ J_4$ is the Jacobian matrix of partial derivatives of real and reactive power with respect to the voltage magnitude and angles. The detail of computation of Jacobian elements is reported in [14, 15]. The small changes in real and reactive power are given by equation (5) and (6) below;

$$\Delta P_i^{(k)} = P_i^{specified} - P_i^{calculated} \qquad (5)$$

$$\Delta Q_i^{(k)} = Q_i^{specified} - Q_i^{calculated} \qquad (6)$$

The new estimate for bus voltages is obtained thus;

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta \delta_i^{(k)} \qquad (7)$$

$$V_i^{(k+1)} = \left|V_i^k\right| + \Delta\left|V_i^k\right| \qquad (8)$$

With equation (9) below, transmission loss is computed. It is viewed as loss of revenue by the utility and it is an explicit function of unit of power generation.Basically, penalty factor method and the B-coefficients method are two known methods for evaluating transmission losses [9]. The latter method is adopted in this work and is given thus;

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_j \qquad (9)$$

Expanding this Kron's loss formula, the system transmission real power lossis expressed as;

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} B_{ij} P_i P_j + \sum_{i=1}^{n} P_i B_0 + B_{00} \qquad (10)$$

Where n= number of generation buses,P_L = Power transmission loss, $P_i$are the active power delivered at bus *i*, P_j are the active power delivered at bus *j*,B_{ij} is the loss coefficients with the units of reciprocal of Watt/Mwatt,$\boldsymbol{B_o}$ and $B_{00}$are the generalized loss coefficients.

2.1 Mathematical Modelling of Shunt Capacitor into Newton-Raphson Iterative Algorithm for Power Flow Solutions

Reactive power is supplied into the system via shunt capacitors to raise voltages at the defective buses to the acceptable range of $0.95 \leq V \leq 1.05\, p.u.$ With this reactive compensation, the real power transmission loss reduced drastically from uncompensated system. For compensated system, the reactive power supplied transformed equation (3) into (11) represented in polar form thus;

$$Q_i - Qd_i + Qc_i = -\sum_{j=1}^{n} \left|V_i V_j Y_{ij}\right| \sin\left(\theta_{ij} + \delta_j - \delta_i\right) \qquad i = 1,2,3.....,n \qquad (11)$$

Where Qc_i=additional reactive power supplied at bus i^{th}, with the power factor of the system raised from 0.85 to 0.96 for compensation purpose, the sizing of additional reactive power needed to raise voltages at defective buses is evaluated using (12) below;

$$Q_c = P\left[\frac{1}{Pf_{(1)}} sin\left(\frac{1}{cos}\left(Pf_{(1)}\right)\right) - \frac{1}{Pf_{(2)}} sin\left(\frac{1}{cos}\left(Pf_{(2)}\right)\right)\right] \qquad (12)$$

where P= Real Power for uncompensated system,$Pf_{(1)}$ =Uncompensated system (0.85), $Pf_{(2)}$ =Compensated system (0.96),

The capacitance value required for compensation which will be injected at the defective bus in the power load flow program is given thus;

$$C = \frac{Q_C}{2\pi f V^2} \qquad (13)$$

Where f= frequency ($50H_Z$) and V= High voltage of 330kV

2.2 Mathematical Modelling of Load Tap-Changing Transformer (LTCT) into Newton-Raphson Iterative Algorithm for Power Flow Solutions

Load Tap-Changing Transformer (LTCT) was employed to raise voltages at the weak buses due to its inherent abilityto regulate nodal voltage magnitude automatically by varying the transformer tap ratio under load; they are equipped with taps on the winding to adjust either the voltage transformation or reactive flow through the transformer [16]. The tap setting for the LTC transformer range limits is given by;

$$T_{k-min} \leq T_k \leq V_{k-max} \qquad (15)$$

The linearized power flow equations for the nodal power injections equations are given thus;

$$\begin{bmatrix} \Delta P_k \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \end{bmatrix}^{(i)} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & \frac{\partial P_k}{\partial T_m} T_k & \frac{\partial P_k}{\partial V_m} V_m \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & \frac{\partial P_m}{\partial T_k} T_k & \frac{\partial P_m}{\partial V_m} V_m \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & \frac{\partial Q_k}{\partial T_k} T_k & \frac{\partial Q_k}{\partial V_m} V_m \\ \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial \theta_m} & \frac{\partial Q_m}{\partial T_k} T_k & \frac{\partial Q_m}{\partial V_m} V_m \end{bmatrix}^{(i)} \begin{bmatrix} \Delta \theta_k \\ \Delta \theta_m \\ \frac{\Delta T_k}{T_k} \\ \frac{\Delta V_m}{V_m} \end{bmatrix} \qquad (16)$$

With the incorporation of Load Tap-Changing Transformer, the active power loss is given by the equation (13);

$$P_{L_{km}} = P_k + P_m \qquad (17)$$

The sending voltage magnitude (V_k), the receiving end voltage magnitude (V_m) and the tap ratio T_k are related by ;

$$V_k = \frac{V_m}{T_k}\left(\frac{\cos(\theta_k - \theta_m + \propto) tan\, \emptyset - \sin(\theta_k - \theta_m + \propto)}{cos\alpha tan\ \emptyset - sin\alpha}\right) \qquad (18)$$

If the power factor angle ($\emptyset$) and the firing angle (α) are assumed to be constant, then equation (14) becomes;

$$V_k = \frac{V_m}{T_k}\left(\cos(\theta_k - \theta_m) - \sin(\theta_k - \theta_m)\right) \qquad (19)$$

3.0 MATHEMATICAL FORMULATIONS OF ECONOMIC DISPATCH

ELD is a constraint optimization which seeks to minimize the total operating cost of a power system while meeting the total load plus transmission losses within the generator limits. The cost model for power generation is given as;

$$C_{P_{Gi}} = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \qquad (20)$$

where;

$C_{P_{Gi}}$ = the fuel cost of generator i^{th} (Naira/ hours), P_{Gi} =the power generated at generator i^{th}, P_{Gi} =the power generated at generator i^{th}, a_i, b_i *and* c_i = fuel cost coefficient i^{th} *generator*.

For a power system with N numbers of generators, the total fuel is the sum of the cost model for each generator given by;

$$F_{P_{Gi}} = \sum_{i=1}^{N}(a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad (21)$$

The objective function for convex ELD minimizes equation (21) as given by;

$$Min. \quad F_{P_{Gi}} = \sum_{i=1}^{N}(a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad (22)$$

Subject to;

Equality Constraint: This shows a relationship between the power real generated, real power delivered and real power loss as given by;

$$\sum_{i=1}^{n} P_{Gi} = P_d + P_L \qquad (23)$$

where;

P_{Gi} = real power generated at generator i^{th}, P_d = Total real power demand and P_L = Power transmission loss computed using equation (9) above.

Inequality Constraint: These are defined limits on physical devices (such as generators, tap changing transformers and phase shifting transformers etc.) of power system so as to ensure system security. The limit on the generator output is expressed as:

$$P_{Gi}^{min} \le P_{GI} \le P_{Gi}^{max} \qquad (24)$$

Security range of bus voltage is given by:

$$V_i^{min} \le V_i \le V_i^{max} \qquad (25)$$

where P^{min} and P^{max} are the lower and upper limits for active power generation, V^{min} and V^{max} are minimal and maximal acceptable voltage levels at each bus.

4.0 RESULTS AND DISCUSSION

This section presents the results of power flow calculations implemented in MATLAB (R2016b, Version 9.1) for Nigerian 330kV, 24-bus system shown in figure 1 below. It has four thermal generating stations (Egbin, Delta, Afam and Sapele) and three hydro stations (Kainji, Jebba and Shiroro) that interconnect various load points. The MATLAB program was run on a portable computer with an Intel Core2 Duo (1.8GHz) processor, 2GB RAM memory and MS Windows 7 as an operating system.

The accuracy of $1.000e^{-003}$ was specified in the power flow program, the maximum power mismatch of $3.49553e^{-07}$ was obtained and convergence occurred in 5 iterations with Shunt Capacitor while the solutions converged in 4 iterations with injection of Load Tap-Changing Transformers. A Sub-MATLAB based program was also used to evaluate B –loss coefficients and the optimal dispatch generation for each generating unit.

The cost coefficients for the four thermal stations and the corresponding power limits used in this paper are as shown in Table 1. Zero values are assigned for the hydro power stations since it is negligible. As at February 2017, the conversion rate was 497 NGN to 1 U.S. dollar, this was adopted for the calculation of fuelcost

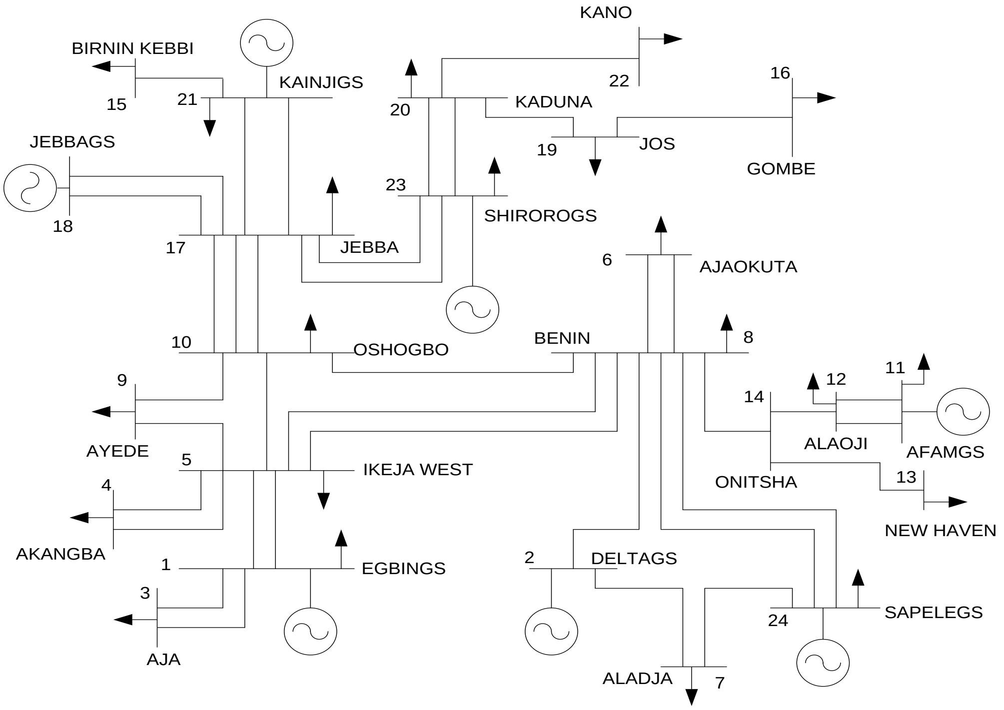

Figure 1: 24-bus 330kV Nigerian transmission system (Source: National Control Centre, Osogbo, PHNC, 2009)

Table 1: Cost Coefficients (Dollar / Hour) and Power limits (MW) for Egbin, Delta, Afam and Sapele respectively.

Thermal Power Stations	a (Dollar/Hour)	b (Dollar/Hour)	c (Dollar/Hour)	P_G^{Max} (MW)	P_G^{Min} (MW)
Egbin	0.007	2	240	1600	100
Delta	0.0095	1	200	1000	50
Afam	0.009	3	220	1000	80
Sapele	0.0076	2	200	1020	50

With equation (9) the B- coefficients were computed from the power flow solutions and when the system was subjected to equality and inequality constraint of equations (23) to (25) respectively optimal dispatch ofgeneration was obtained. At optimal dispatch of generation when the system is subjected to the constraints, the B-loss coefficient obtainedwas $B00 = 0.3655$, the total system loss was85.4206MW, the total cost of generation is30119.497$/hr (N14,969,390.009) and the incremental cost of delivered power (system lambda) is $\frac{12.771464\$}{MWh}\left(\frac{N6347.4176}{MWh}\right)$. Table 2 illustrates a comparisonof optimal dispatches of generation without and with the system reinforced with Shunt Capacitor and Load Tap-Changing Transformer.

Table2: Comparison of B-loss coefficient, total system loss, total cost of generation and incremental cost of delivered power with the system reinforced with LTCT and Shunt Capacitor

Performance Matrics	Optimal Dispatch of Generation with LTCT	Optimal Dispatch of Generation with Shunt Capacitor
$B00$	0.3655	0.3660
Total System Loss (MW)	81.9865	82.5982
The Total Cost of Generation ($/h)	29827.96 (14,824,496.12N/h)	29869.30 (14,845,042.10 N/h)
Incremental Cost of Delivered Power (System Lambda)($/MWh)	12.744292 (6333.9131N/MWh)	12.761801 (6342.6151N/MWh)

A comparison of optimal dispatch of generation of the seven generating stations of Nigerian Grid System without and with Shunt Capacitor and Load Tap Changing Transformer is presented in table 3 below;

Table3: Optimal Load Dispatch of Generation of the seven generation stations

Generating Stations	Optimal Dispatch of generation without reinforcement	Optimal Dispatch of generation with Shunt Capacitor	Optimal Dispatch of generation with LTCT
Egbin (Thermal)	760.8233	760.5332	760.3886
Delta (Thermal)	583.3717	583.3778	582.4995
Afam(Thermal)	530.8710	582.1078	531.0518
Sapele (Thermal)	599.5703	599.4037	598.7708
Kainji(Hydro)	592.0173	592.1265	591.1273
Jebba(Hydro)	614.3687	614.3578	614.4422
Shiroro(Hydro)	605.0984	605.1271	604.4127

The effect of system reinforced with Shunt Capacitor and LTCT on the voltage profile of the system is presented in table 4 below. A significant improvement is observed where voltage magnitude fall below the minimum acceptable range with the system reinforced with Shunt Capacitor and LTCT, much improvement is seen with LTCT than that of Shunt Capacitor.

Table 4: Effect of Shunt Capacitor and Load Tap-Changing Transformer on System Voltage Profile

Bus No/ name	**Voltage Mag. Without reinforcement**	**Voltage Mag. With Shunt Capacitor**	**Voltage Mag. With LTCT**
13(New Haven)	**0.929**	**0.999**	**1.014**
16 (Gombe)	**0.866**	**0.975**	**0.986**
22 (Kano)	**0.880**	**0.987**	**1.027**

At the optimal economic load dispatch, the total system loss reduced by 2.8224 which is 3.3% reduction with incorporation of Shunt Capacitor, while with LTCT, the total system loss reduced by 3.4341 which is 4.02% reduction.

Total cost of generation reduced by 0.97% with the system reinforced with LTCT while with Shunt Capacitor incorporation the total cost of generation reduced by 0.83%, the summary is presented in table 5 below.

Table5: Summary of the results Total Cost of Generation and Total System Loss with and without reinforcement at Optimal Dispatch of Generation

Performance Matrix	**Nigerian 330kV Grid system without reinforcement**	**Nigerian 330kV Grid system reinforced with Shunt Capacitor**	**Nigerian 330kV Grid system reinforced with LTCT**
$\boldsymbol{P_{FL}}$–(Optimal Economic Dispatch of Generation (WM))	85.4206	82.5982	81.9865
$\boldsymbol{F_{TF}}$–(Optimal Economic Dispatch of Generation ($/h)	30119.497	29869.30	29827.96
% Reduction in the system total system losses	-	3.3	4.02
% Reduction in the system total cost of generation	-	0.83	0.97

5.0 CONCLUSION

A Comparative Application of Shunt Capacitor and Load Tap – Changing Transformer (LTCT) tothe Optimal Economic Dispatch of Generation on Nigerian330kV, including transmission losses was presented in this paper.The results of the analysis showed that with the system reinforced with LTCT, the total system generation cost and the system transmission losses reduced by 0.97% and 4.02% respectively and the percentage reduction observed with the system reinforced with Shunt Capacitor are 0.83% and 3.3% respectively.

The effect of system reinforced with LTCT and Shunt Capacitor bring an appreciable improvement on system voltage profile at buses where voltage magnitude (Example are the buses 13 (New Haven), 16 (Gombe) and 22 (Kano)) fall below the acceptable range of $0.95 \leq V \leq 1.05\ p.u$

However, application Load Tap-Changing Transformers (LTC) were found to save a substantial amount of money as seen in the total cost of generation with appreciable improvement in system's voltage profile accompanied with significant reduction in total power losses than that observed when the system was reinforced with shunt capacitor.

REFERENCE

[1] Hamid B, Abdelkader C, Ahmed A and Bakhta N (2005):" Economic Dispatch Solution using a Real – Coded Genetic

Algorithm", Electrotechnical Department ,Faculty of Electrical Engineering , USTO, B.P. 1505 ElM'naouar , Oran, Algeria

[2] ReddyD. P and Suresh M. C. V (2015): "Economic Load Dispatch with Valve Point Effect using Firefly Algorithm", International Journal of Engineering Sciences & Research Technology, Vol.4, Issue2, Pp. 557-560

[3] Subramanian R, Thanushkodi K and Prakash A (2013): "An Efficient Meta Heuristic Algorithm to Solve Economic Load Dispatch Problem",Iranian Journal of Electrical& Electronic Engineering, Vol. 9, No. 4, Pp.246-252

[4] Kothari D.P, Dhillon J.S (2011): "Power System Optimization", second edition, PHI learningprivate, Pp. 536-591

[5] X.-S. Yang (2010):"Firefly Algorithm, Levy Flights and Global Optimization", Research andDevelopment in Intelligent Systems XXVI(Eds M. Bramer, R. Ellis, Petridis), SpringerLondon, Pp. 209-211

[6] EI-Hawary M.E and Christensen G.S (1979): "Optimal Economic Operation of ElectricPower System", New York Academic

[7] Chiang C-L (2007): "Genetic–based algorithm for power economic load dispatch", IEEProceeding on Generation, Transmission andDistribution, Vol.1,No.2, Pp.261-269.

[8] Selvakumar A.I and Thanuskodi K (2007):"A new particle swarm optimization solution to non-convex economic dispatch problem", IEEETransactions on Power System, Vol.22, No.1,Pp.42-50.

[9] Ajenikoko G. A and Olabode O.E (2016): "Optimal Power Flow with Reactive PowerCompensation for Cost and Loss Minimization onNigerian Power Grid System",International Journal of Science and Engineering Invention (IJSEI), Vol. 02, Issue 09 Pp.107-119

[10] Roy P.K., Ghoshal S.P and Thakur S.S (2010): "Biogeography based optimization for multiconstraint optimal power flow with emissionand non-smooth cost function, "ExpertSystems with Applications" Vol.37, No.12,Pp. 8221-8228

[11] Susheel K D, Achala J and Huddar A.P (2015): "A Traditional Approach to Solve Economic Load Dispatch Problem Considering the Generator Constraints", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)e-ISSN: 2278- 1676, p-ISSN: 2320-3331, Volume 10, Issue 2 Ver. III, Pp. 27-32.

[12] Adebayo I.G, Adejumobi I.A and Adepoju, G.A (2012): "Application of Load Tap – Changing Transformer (LTCT) tothe Optimal Economic Dispatch of Generation of the Nigerian 330kV gridSystem",International Journal of Emerging Technologies in Sciences and Engineering, Vol.5, No.3, Pp. 40-50.

[13] Olabode O.E, Oni D.I and Obanisola O.O (2017): "An Overview of Mathematical Steady-State Modelling of Newton- Raphson Load Flow Equations Incorporating LTCT, Shunt Capacitor and FACTS Devices", International Journal of AdvancedResearch in Science, Engineering and Technology, Vol.4, Issue 1, Pp.3163-3176

[14] Saadat H. (2006): "Power System Analysis", New York: McGraw-Hill Publishing Company Limited, New York

[15] Nagrath. I and Kothari D (2006): "Power System Engineering", New York McGraw-Hill

[16] Olabode O.E, Nwagbara V.U and Mathew T.O(2017): "Comparative Application of Load Tap-Changing Transformer (LTCT) and Shunt Capacitor for Voltage Profile Enhancement on Nigerian 330kV, 24-Bus Transmission System", International journal of scientific and technical research in engineering (IJSTRE), Vol.2, Issue1, Pp.17-29

s