AN ABC BASED ACTIVE AND REACTIVE POWER ENHANCEMENT WITH OPTIMALLY DESIGNED DISTRIBUTED GENERATION AND DSTATCOM FOR 11KV YANTUKWANE NETWORK IN KADUNA, NIGERIA

ISAAC I. ALABI, YAHAYA S. ABDULSALAM AND ABEL E.AIROBOMAN

Corresponding Author: engribitayo@gmail.com, abdulyaha@gmail.com, airobomanabel@nda.edu.ng,

ABSTRACT

In this paper the optimal placement of Distributed Generation (DG) and Distributed Static Compensator (DTATCOM) in the Yantukwane 11kkV feeder, Kaduna was carried out using Artificial Bee Colony (ABC) optimization Technique. The paper utilized the Loss Sensitivity Index (LSI) LSI and Load Flow Analysis (LFA) for identification of buses with higher losses. The proposed method was tested on the IEEE 33- bus radial distribution system, thereafter on the Yantukwane 11kV distribution network. The IEEE test results of the proposed method demonstrated better loss reduction and voltage profile improvement. The results from the Yantukwane network indicated a power loss reduction of approximately 64%. Also the minimum value of voltage magnitude without compensation was found to be 0.8432p.u, and after compensation the value become 0.9498p.u indicating the voltage profile improvement of approximately 11%. Thus, the study demonstrated the potential of Distributed Generation and Distribution Static Compensator to effectively reduce power loss and improve voltage profile in the radial distribution system.

Keywords: DG, Loss, Minimization, Optimization,

INTRODUCTION

Modern power systems in developing countries such as Nigeria are confronted with numerous operational problems because of their rapid growth rates. This operational problem is further compounded by increase in rural to urban migration that has led to an excessive demand of electrical energy. Unfortunately the supply authorities have been struggling to meet the demand of consumers to no avail the consequence at times would lead to the lines been overloaded resulting to epileptic power supply, poor power quality, or even total power outage, therefore causing loss of supply of energy to the consumers.

In electrical distribution system, one of the key measures of distribution system performance is the amount of energy loss, as it has a direct impact on the consumer base line. Distribution system's losses can be attributed to technical and non-technical reasons. Since losses represent a considerable amount of operating cost, accurate estimation of electrical losses enables electrical company to determine with greater accuracy the operating costs for maintaining supply to consumers. It is also critical to know if the expected target of technical losses is indeed technical, as such conclusion could be drawn whether it is possible to reduce the loss without changing the system configurations. Lower technical losses will provide for cheaper electricity and lower production costs, with a positive influence on economic growth [1].The two components of power loss are; Technical and Non-Technical power losses [2]. Technical power losses (TL) are natural losses and consist mainly of power consumed in the system components or equipment such as Transmission and Distribution lines, transformers, power control equipment and measurement component. Technical powers losses occur during transmission and distribution processes. Most of losses are resistive losses of the primary feeders, transformer losses (resistive losses in windings and the core losses), resistive losses in the secondary network (in Nigeria, typically 33kV & 11kV networks), resistive losses in service drops to customers premises and losses in kWh Meter. Technical power losses are also classified as copper losses (I^2R), Dielectric losses and induction and radiation losses. However, the technical power losses known PS have different causes and these include harmonic distortion, improper earthing of electrical equipment at various substations, unbalanced loading of distribution transformer and defected equipment such as aluminium conductor, cable and so on. All these losses have serious consequences on the quality of power disseminated to customers and adverse effect in meeting the expected company's revenue targets the economy problems [2]. The term power quality as a general concept can be described as provision of voltages and systems design so that electricity consumer can utilize electric energy from the distribution system without interruption [3]. Power quality enhancement becomes necessary in power systems engineering to meet up the increasing demand for electricity needs because of the growing populace of which the power system in the context of this article the distribution company to meet up its consumer needs. One of the ways which the world of engineering has devised is by bringing distributed generation closer to the loads or source of consumption.

This paper considers the 11kV Yantukwane distribution network connected with Distributed Generation (DG) and Distribution Static Compensator (DSTATCOM) as the FACT device. DSTATCOM is used in this research because of its quicker response time and compact structure. The main purpose of using FACTS devices is to replace the existing slow devices like capacitor that required to react to the changing system conditions [4]. The FACTS devices can dynamically control line impedance, line voltage, active power flow and reactive power and when storage becomes economically viable, they can supply and absorb active power as well [4]. With the use of fast acting controls, the power system security margins could be enhanced by utilizing the full capacity of transmission/distribution lines maintaining the reliability of power supply. For electric power networks to satisfy the general increasing demand, various algorithms or methods have been adopted, design and implemented. Distributed Generation (DG) is one of these methods which have many advantages such as loss reduction, improving voltage profile, and increasing reliability. Besides renewable energy sources like solar cells, wind turbines, fuel cells, and small hydro turbines can be used as a DG unit. Placement of DG unit will change the power loss profile of any distribution system. Hence, if the size of DG is more than the optimum size, it will create reverse flow of power towards distribution substation [5].

More specifically, the Artificial Bee Colony Algorithm is proposed for the optimal sizing and siting of the DG and DSTATCOM for power loss minimization and voltage profile improvement for the Yantukwane distribution network while loss sensitivity index will be used to identify the buses with higher loss sensitivity indices.

LITERATURE SURVEY

In [7], the paper proposes a loss reduction and enhancement scheme for bus voltages in the active radial distribution network (RDN). A DG is used for the elimination of network losses and the DSTATCOM for the under-voltage problem of which direct load flow technique is used for load flow calculations and LSF is used for placement of DG on the MATLAB platform along with voltage deviation. However the research was implemented on IEEE 33-bus radial distribution network only.

The research [6] present approaches that use bat algorithm for optimal sizing of DSTATCOM to reduce the total power loss of the system in the radial distribution systems. Voltage stability factor (VSF) is utilized to identify the optimal siting for installation of DSTATCOM. To verify the validity of the proposed method, it has been implemented on standard IEEE 33-bus RDS. The result obtained shows that the optimal location of DSTATCOM in RDS adequately reduce power loss and at the same time improve the bus voltages. Therefore, the algorithm was more effective for enhancing the voltage profile of a distribution networks.

Also, [7] presented an analytical approach for location of D-STATCOM in a radial distribution network to minimize losses and improve voltage profile. The performance was tested on a 33-bus system. The research considered the use of DSTATCOM to generate reactive power as against the use of series voltage regulators or shunt capacitors which can maintain voltages at a suitable range in distribution network but cannot generate reactive power. It can only force the source to generate the requested reactive power. Another problem with distribution capacitors is its oscillatory nature when used in the same circuit with inductive components hence the preference for a DSTATCOM. The research did not consider the case of local distributed network.

The research [8], proposed a hybrid of a fuzzy multi-objective approach and ant colony optimization as a meta-heuristic algorithm was used to solve the simultaneous reconfiguration and optimal allocation (size and location) of photovoltaic arrays as a distributed generation DG and DSTATCOM as a FACT device in a RDS. The research was implemented to reduction power loss, voltage profile improvement and improving in the feeder load balancing. The research method was validated using the IEEE 33-bus test system and a Tai-Power 11.4-kV distribution system as a real distribution network. Simultaneous reconfiguration and optimum allocation of the PV array and DSTATCOM unit have been shown to lead to substantially reduced losses, improved VP, and increased load balance. However, the algorithms process is tedious for real-time implementation of the scheme.

The research [9] proposed an approach that employed ABC algorithm to determine the "Optimal DG unit's size and location in order to minimize the total system real power loss and improve the voltage profile" and tested on IEEE 34 bus system using ETAP 12.6 and MATLAB to check the reliability of the algorithm. They were able to achieve voltage profile improvement of small amount and significant reduction in real power losses.

Also, the research [10] proposed a Particle Swarm Optimization (PSO) approach for optimal location and sizing of distributed generation (DG) and DSTATCOM to facilitate the minimization of the line loss and voltage dips in radial distribution systems. That is, the real power was provided by DG and reactive power was compensated by DSTATCOM. Location and sizing of DG and DSTACOM was achieved by PSO and test run on IEEE test buses for 12, 34 and 69 buses respectively. The results showed better voltage profile improvement and reduction in total power loss of the system.

The research [11] proposed a novel approach to power quality enhancement in Grid connected PV systems using high step up DC-DC converter to improve the voltage generated from a PV system and used Matlab/Simulink to perform this objective using one switch from the converter that leads to low switching noise. The work considered only single objective; power quality enhancement.

In research [12], sizing and sitting issue of DG placement in radial distribution systems using novel method with an objective to minimize the active and reactive power loss and enhance voltage profile of overall system was worked upon. The effectiveness of the novel method was successfully tested on IEEE 33 bus radial distribution system in ETAP software and the results are found to be in very good agreement but the test was not extended to the local problems.

From the above review, several optimization works have been implemented to identify the siting and sizing problem of compensating devices in the RDS. Although, most of the research reviewed uses various algorithm to solve IEEE test bus system and did not address the problem to local distribution network. To overcome the above said drawbacks, the present work introduces an efficient and nature inspired optimization approach called artificial bee colony to resolve optimal siting and sizing of DSTATCOM and DG problems in the RDS with a view to minimizing active power loss and voltage profile improvement and as a case study to apply it to the 11kV Yantukwane distribution feeder of Kaduna electricity distribution network which is currently experiencing overloading.

MATERIALS AND METHODS

The materials and methods employed in order to achieve the objectives set out in this research are also discussed. This involves modelling of the DSTATCOM, Backward-Forward Sweep (BFS) Technique for Power Flow Analysis, Sensitivity analysis to identify weak feeders and also Artificial Bee Algorithm to place and size the DSTATCOM and DG which will compensate for losses and improve voltage profile in a radial distribution network. The single line data obtained from 11kv Yantukwane distribution network of Kaduna Electricity Distribution Company are presented as well as the steps to be followed in the implementation of the already chosen optimization techniques.

The 11kV Yantukwane distribution network was considered as a case study in this research. The feeder supplies different substation and it is radiated from 15MVA/11kV injection substation Transformer located at Kinkinau area. The Kinkinau injection substation is supplied by 33kV line from Transmission Company of Nigeria (TCN), Mando, Kaduna State, Nigeria. The line and bus data were collected from the station while the Newton Raphson (NR) algorithm in line with equations (1) and (2) were used to determine the real and reactive power of the network using Matlab Software. The Single line diagram and bus data of the network are presented in Appendices I & II.

$$P_i = ?_{j=i}^{n} |V_i||V_j||Y_{ij}| \cos\left(?_{ij} + d_j - d_i\right) \qquad (1)$$

$$Q_i =- ?_{j=i}^{n} |V_i||V_j||Y_{ij}| \sin\left(?_{ij} + d_j - d_i\right) \qquad (2)$$

Equations (3) – (5) presents the mathematical modeling of the injected power by the DSTATCOM which has been known to comprise of a Voltage Source Converter (VSC) and Energy Storage System (ESS).

$$JQ_{DSTATCOM} = V_{jnew} I^{*}_{DSTATCOM} \qquad (3)$$

$$V_{jnew} = V_{jnew} < a_{new} \qquad (4)$$

$$I_{DSTATCOM} = I_{DSTATCOM} < \left(a_{new} + \frac{p}{2}\right) \qquad (5)$$

Furthermore, the optimal size was calculated by considering the variables kVAR and kW for DSTATCOM and DG respectively. The objective of calculating the optimal size of DSTATCOM and DG was improvement in overall voltage profile of the distribution network, minimization of the network losses and energy cost. The size of the DSTATCOM can be calculated using the equation (6).

$$jq_{DSTATCOM} = V'_{m+1}\, i^{*}_{DSTATCOM} \quad (6)$$

The size of DG will be P_{DG} when the function F3 has maximum value in Equation (7).

$$Max\{F_3\} = C_E * P_{PLR} * 8760 - C_{DG} * P_{DG} * ? \quad (7)$$

Where; C_E = Cost of the energy (INR/kW h), P_{PLR} = Power loss reduction after the installation of DG, C_{DG} = Capital cost of the DG (per kW), P_{DG} = Total capacity of the DG (kW), ɤ = Annual rate of depreciation & interest charges.

The objective function (F) of total active power loss in an electric power network was formulated using (8)

$$min\{F_2\} = \left(\frac{P'_{loss}}{P_{loss}}\right) * (0.01) + \left[\sum_{i=1}^{nb}\{(Vi - Vmin)^2 + (Vi - Vmax)^2\}\right] \quad (8)$$

Where, P_{loss} = total real power loss of system before DG Placement, P'_{loss}= total real power loss of system after DSTATCOM installation, V_{min}= Minimum permissible voltage limits, V_{max} = Maximum permissible voltage limits, nb = total number of buses in the system. These was however subjected to the following constraints as presented in equations (9) – (11)

Power flow limit:
The apparent power transmitted through branch i shall not surpass the limiting value, S_{lmax}, which reflects the thermal limit of the steady-state operating line or transformer.

$$S_l = S_{lmax} \quad (9)$$

Bus voltage limits
For several reasons such as stability and power equality, the bus voltages must be maintained around the nominal value for the purpose of power equality and stability given by equation (10).

$$V_{imin} = V_{inom} = V_{imax} \quad (10)$$

For i= {1,2,3,……,N_b}

Where, V_{imin}, V_{imax} = minimum and maximum voltages limits of i^{th} node of the network respectively and V_i = voltage at i^{th} node and N_b= number of buses.

The LSF for all nodes were calculated using (11) – (13) to determine the optimal location for the placement of the DG and DSTATCOM

$$Pi = \frac{1}{\alpha_{ij}}\left[\beta_{ij}Q_i + \sum_{\substack{j=1\\ j=i}}^{n}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (11)$$

Where, Pi represents the real power injection at node i, which is the difference between real power generation and real power demand at that node.

$$P_i = P_{DGi} - P_{Di} \quad (12)$$

Where, P_{DGi} = is the real power injection from DG placed at node i, P_{Di} = the load demand at node i, Therefore, P_{DGi} is given by equation (13)

$$P_{DGi} = P_{D\,i} + \frac{1}{\alpha_{ij}}\left[\beta_{ij}Q_i - \sum_{\substack{j=1,\\ j\neq 1}}^{n}\left(\alpha_{ij}P_j - \beta_{ij}Q_j\right)\right] \quad (13)$$

The flow chart used for the sizing of the DSTATCOM and DG is presented using Appendix III.

RESULTS AND DISCUSSION

Table I shows results obtained on the IEEE 33-bus network. The results were compared with those of [7]- [8] for the same IEEE 33-bus system to establish the effectiveness of the current method. Hence, when compared with all the cases, power loss reduction and improvement in the voltage profile by approximately 11.7% and 3.5% was achieved respectively when both the DSTATCOM and DG were placed in the distribution network. Therefore, the current method demonstrated a better power loss minimization and voltage profile improvement. The method was then applied to the 11kV Yantukwane feeder of Kaduna Electricity Distribution network. The load flow solution as shown in Appendix IV comprises voltage magnitude and angle for all the buses, real and reactive power flows on lines, real and reactive power losses on lines and total real and reactive power losses. The summary of the results is then presented using Table II.

Table 1: Summary of simulation results of the ieee 33-bus test system before and after compensation

IEEE 33 BUS TEST SYSTEM	BEFORE PLACEMENT OF DG AND DSTATCOM	AFTER PLACEMENT OF DG AND DSTATCOM
DG bus Location	———	3
D-STATCOM bus location	———	6
Size of DG (kW)	———	1000
Size of DSTATCOM (kVAr)	———	650
Total losses (kW)	218.8634	67.8235
Power loss reduction	———	69.011%
Voltage (p.u)	0.8875	0.958
Voltage Improvement	———	7.3591%

TABLE 2: Summary of simulation result of yantukwane distribution network before and after the compensation

YANTUKWANE SYSTEM	BEFORE PLACEMENT OF DG AND D-STATCOM	AFTER PLACEMEN OF DG AND D-STATCOM
DG Bus location	______	13
D-STATCOM Bus location	______	5
Size of DG (kW)	______	1000
Size of DSTATCOM (kVAr)	______	550
Total loss (kW)	559.3519	201.9875
Power loss reduction	______	63.8890%
Voltage (p.u)	0.8432	0.9498
Voltage Improvement	______	11.2234%

Table II shows the total active power loss before the optimal placement of DG and DSTATCOM was 559.3519 kW. When the optimization algorithm changes the values of DG and DSTATCOM ratings to optimal size of 1000kW and 550kVAr respectively, the value of the total active power loss with both DG and DSTATCOM optimally placed in the network is 201.9875kW indicating a power loss reduction of approximately 64%. Also, the voltage magnitude without compensation was found to be 0.8432p.u, and after compensation the voltage magnitude became 0.9498p.u indicating the voltage profile improvement of approximately 11%. Figure 1 show the real power loss sensitivity index for Yantukwane distribution system, the bar chart shows that bus 13 and bus 5 has the highest real power loss sensitivity indices, based on this the DG which is meant to inject real powers would be placed in bus 13. Should there be need for a second DG it will be placed in bus 5.

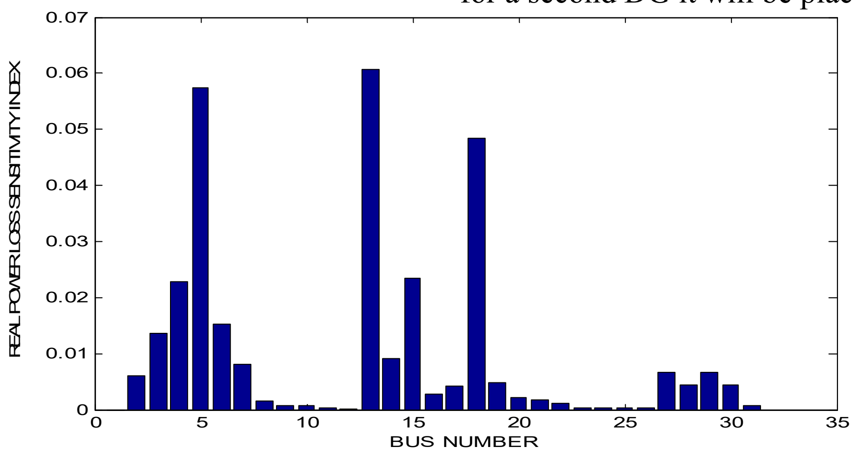

Figure 1: Real power loss sensitivity index.

Figure 2 represents the reactive power loss sensitivity index for Yantukwane distribution system, the bar chart shows that bus 5 and bus 13 has the highest reactive power loss sensitivity indices, based on this bus 13 having higher reactive loss sensitivity indices, the DSTATCOM which is meant to inject reative powers will be placed in bus 5 since bus 13 has been occupied by DG. Should there be need for a second DSTATCOM it will be placed in bus 18.

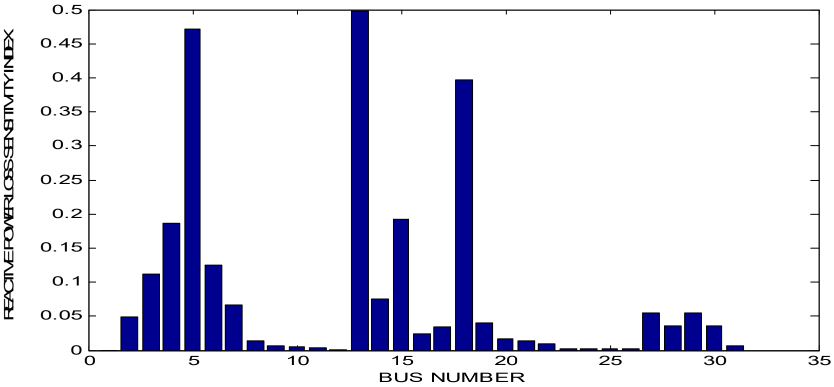

Figure 2: Reactive power loss sensitivity index.

Figure 3 shows voltage profile plotted when DG and DSTATCOM are optimally placed in bus 13 and bus 5 respectively using loss sensitivity index. The value of the voltage magnitude obtained without DG and DSTATCOM is 0.8432p.u at bus 12 but, when the DG and DSTATCOM was placed in the network, the voltage magnitude becomes 0.9498p.u indicating 11.2234% voltage profile improvement.

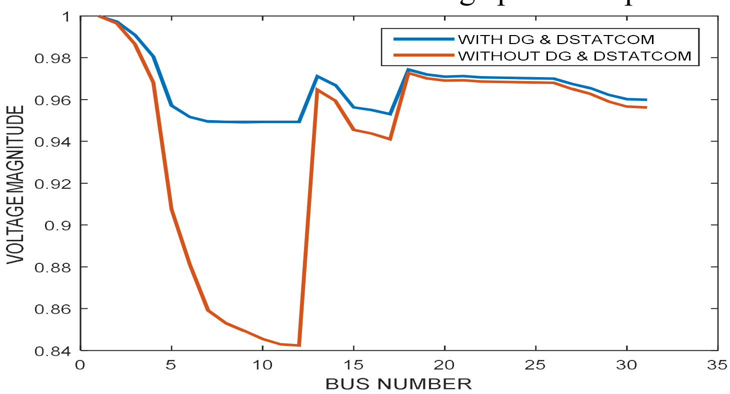

Figure 3: Voltage profile with and without compensation

Figure 4 is the ABC optimization process which shows how the real power losses on the line is been reduced to 201.9875kW as the optimization algorithm changes the values of DG and DSTATCOM ratings to optimal size of 1000kW and 550kVAr respectively. The losses came down to 201.9875 kW from 559.3519kW.

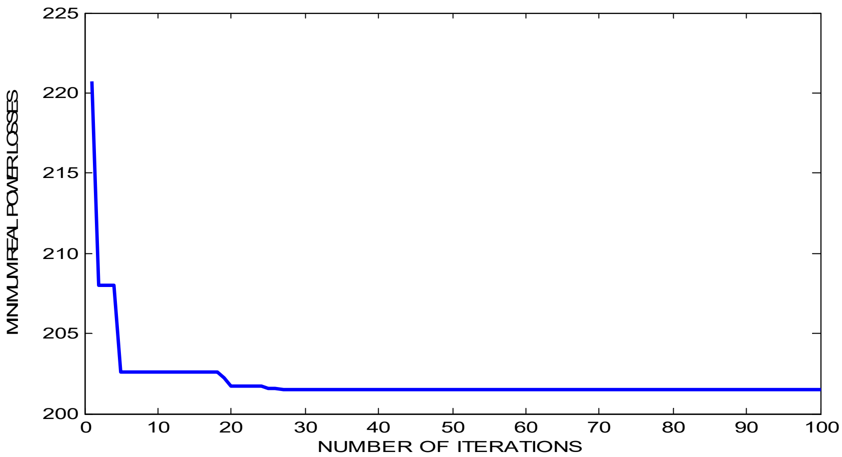

Figure 4: ABC optimization process plot.

CONCLUSION

This paper presents the optimal siting and sizing of DG and DSTATCOM for power loss minimization and voltage profile improvement as a power loss solution to the 11kV Yantukwane distribution system of Kaduna Electricity distribution network. The optimal values or size of DG and DSTATCOM ratings obtained by optimization algorithm was 1000KW and 550KVAr respectively. The total active power loss minimization was reduced from 559.3519 kW to 201.9875kW indicating a power loss reduction of approximately 64% and the voltage profile was improved from 0.8432p.u to 0.9498p.u represents 11.2234% improvement. However, the methodology was tested on IEEE 33-bus radial distribution systems and the result obtained where compared with those obtained in the previous study. The active power loss reduction obtained was 67.8235kW which represents 69.011% power loss reduction and voltage profile improvement of 7.3591%. Therefore, the research demonstrated the potential of the ABC algorithm using DSTATCOM and DG to effectively reduce power loss and improve voltage profile in radial distribution system.

REFERENCES

[1]. Dikio C. I, Aderemi J. O, Biobele A. “Forecasting of Electrical Energy Demand”. *American Journal of Engineering Research (AJER)* e-ISSN: 2320-0847 p-ISSN : 2320-0936 Volume-7, Issue-1, pp-122-135, 2018

[2]. Abdulkareem A. & Adeshina L.M. “Determination of Power System Losses in Nigerian Electricity Distribution Networks” *International Journal of Engineering & Technology*. 2016.

[3]. Saifullah K., Bharti D. “Power quality issues, problems, standards & their effects in industry with corrective means”. Department of Electrical Engineering, I.E.T., Lucknow, India. 2011.

[4]. Zhang P., Li W.Y., Wang S.X. “Reliability-oriented distribution network reconfiguration considering uncertainties of data by interval analysis”. *International Journal of Electrical Power Energy System*, 34, 138–144. 2012.

[5]. Fahad I., Mohd T.K, Anwar S.S. “Optimal placement of DG and DSTATCOM for loss reduction and voltage profile improvement”. Department of Electrical Engineering, Jamia Millia Islamia, New Delhi, India. *Alexandria Engineering Journal* 57, 755–765, 2017.

[6]. Yuvaraj, T., K. Ravi, and Devabalaji K.R. ‘’DSTATCOM Allocation in the Radial Distribution Networks with Different Stability Indices using Bat Algorithm’’ *journal of Science GU J Sci* 30(4): 314-328,2017.

[7]. Mimhasmi M.R, Hajar B.T., "Simultaneous Reconfiguration, Optimal Placement of DSTATCOM, and Photovoltaic Array in a

[8]. Distribution System Based on Fuzzy-ACO Approach," *IEEE Transactions on Sustainable Energy*, Volume - 6, no. 1, pp. 210-218, 2015.

[9]. Manohara M., Deepika K., Dr Devaraju T. “Optimal Placement Of DSTATCOM And Load Flow Analysis Of Radial Distribution Networks”, *International Journal of Engineering Science and Technology (IJEST)*, 0975-5462, Volume- 4 No.06 June 2012.

[10]. Sajeevan S., Padmavathy N. “Optimal allocation and sizing of distributed generation using artificial bee colony algorithm”. *International Research Journal of Engineering Technology. (IRJET),* 3, 1244–1252. 2016.

[11]. Devi S. and Geethanjali M. "Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization

algorithm." *International Journal of Electrical Power & Energy Systems*, 62: 562-570, (2014).

[12]. Prasadarao K V S. "Power quality enhancement in grid connected PV systems using high step up DC-DC converter", *International Journal of Electrical and Computer Engineering, Research Gate Journal International Journal of Engineering Research & Technology (IJECE),* ISSN:2088-8708, Volume- 7, No.2, pp, 720-728, April 2017.

[13]. Azra Z. and Sridevi J. "Novel Method for Loss Reduction and Voltage Profile Improvement with Multiple DGs". *International Journal of Scientific & Engineering Research*, Volume-8, Issue 11, November-2017, 843 ISSN 2229-5518 IJSER © 2017.