Journal of Theoretical and Applied Information Technology

www.jatit.org

SIZING OF DG UNIT OPERATED AT OPTIMAL POWER FACTOR TO REDUCE LOSSES IN RADIAL DISTRIBUTION. A CASE STUDY

A. Lakshmi Devi[1] and B. Subramanyam[2]

1Department of Electrical and Electronics Engineering, SVUCE, Tirupati, India
2Narayana Engineering College, Gudur, India
E-mail: energylak@yahoo.co.in

ABSTRACT

Distributed generators are very much beneficial in reducing the losses effectively compared to other methods of loss reduction .In this paper optimal size of DG unit operated at optimal power factor is dealt. DG unit placement using fuzzy logic and sizing of DG at any power factor is calculated using analytical method . Voltage and power loss reduction indices of distribution system nodes are modeled by fuzzy membership functions. Fuzzy inference system containing a set of rules is used to determine the DG unit placement. DG units are placed at buses with the highest suitability index. Simulation results show that optimal DG unit placement and sizing at 0.8 power factor is very efficient. Single DG unit of optimum size operated at 0.8 power factor is sufficient in reducing losses and improving voltage regulation effectively within the specified voltage constraints.

KEYWORDS : *Distributed generation (DG)unit, ,Power loss, Loss reduction, Voltage regulation*

ACRONYMS

I --- Branch Current
I_a --- Active part of branch current
I_r --- Reactive Part of branch Current
R --- Resistance of the branch
X --- Reactance of the branch
P_L --- Total Power Loss
V --- Voltage
$P_{L a}$ --- Total Power Loss due to active component Current
$P_{L r}$ --- Total Power Loss due to reactive component Current
TAPLBC --- Total Active Power Loss before Compensation
TRPLBC --- Total Reactive Power Loss before Compensation
TAPLAC --- Total Active Power Loss after Compensation
TRPLAC --- Total Reactive Power Loss after Compensation
APLR --- Active Power Loss Reduction
RPLR --- Reactive Power Loss Reduction
%APLR ---Percentage Active Power Loss Reduction
%RPLR ---Percentage Reactive Power Loss Reduction
VRBC ---Voltage Range before Compensation P.U
VRAC ---Voltage Range after Compensation P.U
VBC AT CB ---Voltage before Compensation at the Compensated Bus
VAC AT CB ---Voltage after Compensation at the Compensated Bus
%VI --- Percentage Voltage Improvement

KVA-Kilo volt Ampere
KW - Kilo Watts
K Var-Kilo Volt ampere reactive

1. INTRODUCTION

Distribution system provides a final link between the high voltage transmission system and the consumers. A radial distribution system has main feeders and lateral distributors. The main feeder originates from substation and passes through different consumer loads. Laterals are connected to individual loads. Generally radial distribution systems are used because of their simplicity. Power loss in a distribution system are high because of low voltage and hence high current. There are many methods of loss reduction techniques used like Feeder reconfiguration, capacitor placement, high voltage distribution system, conductor grading and DG unit placement. All these methods are involved with passive elements except DG unit placement .Both DG Units and capacitors reduce power loss and improve voltage regulation. The over all efficiency can be improved using DG units. Earlier studies show that with capacitors [1]-[3] loss reduction is possible. Recently attention shifted to DG units which can be used for loss reduction and also in improving voltage profile of the system [18]-[20].

2. METHODS OF REDUCING LOSS USING DG UNIT

Many methods have come in recent times on DG unit placement. [18] proposed a method to calculate the size of DG Units analytically by using exact loss formula which requires lot of computation compared to the proposed analytical method. Many authors like [15] mentioned the allocation of DG units using Genetic algorithm. They have not considered the optimum size; they have addressed the problem in terms of cost. [7] They have iteratively increased size of the DG at all buses and then they calculated the losses, based on loss calculation they ranked the nodes. Top ranked units are selected for DG unit placement. Here optimum sizes of the DG units are calculated using a new analytical method. A new of method of minimizing the loss associated with the absolute value of branch currents by placing optimal DG units operated at any power factor at proper locations. Here cost function is not considered. Considering the cost function involves the deviation of exact size of the DG unit at suitable point.

3.1DG UNIT INSTALLATION

The problem of DG unit placement consists of determining the locations and sizes and number of DG units to install in a distribution system such that maximum benefits are achieved while operational constraints at different loading levels are satisfied.

Distribution losses

The total power loss in a distribution system having a ‘n’ number of branches is given by

$$P = \sum_{i=1}^{n} I_i^2 R_i \qquad (1)$$

Ii is the current magnitude and Ri is the resistance. Ii can be obtained from load flow study. The branch current has two components .active (I_a) and reactive (I_r)

The loss associated with these two components can be written as

$$P = P_{La} + P_{Lr}$$

$$P = \sum_{i=1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \qquad (2)$$

For a given configuration of a single source radial network the loss P_{La} associated with the active component of branch currents cannot be minimized because all the active power must be supplied by the source at the root bus. This is not true if DG units are to be placed at different nodes for loss reduction that is real power can be supplied locally by using DG units of optimal size to minimize P_{La} associated with the active component of branch currents [19].

3.2 PLACEMENT OF DG UNITS AT OPTIMUM LOCATIONS USING FUZZY LOGIC

There are many uncertainties in various power system problems .Because of this it becomes very difficult to stick to mathematical formulae alone. To over come this, fuzzy set theory has been applied to many power system problems. Using fuzzy expert system a set of heuristic rules is used to determine the DG unit placement suitability index at each node in the distribution system .Rules are defined to determine the suitability of a node for DG unit installation. Those rules are expressed in the following form.

IF premise (antecedent), THEN conclusion (consequent). For determining the suitability of Dg unit placement at a particular node, a set of multiple antecedent fuzzy rules has been established. the inputs to the rules are the voltage and power loss indices.

The fuzzy variables, power loss index, voltage and DG unit suitability are described by the fuzzy terms high, high-medium/ normal, low-medium/normal or low. These fuzzy variables are described by membership functions. DG units are placed at the nodes with the highest suitability. Voltage and power loss reduction indices of distribution system are modeled by fuzzy member ship functions.

FIS editor receives inputs from the load flow program. Several rules may fire with some degree of membership. FIS is based on Mamdani max-min and max-prod implication methods of inference. These methods determine the aggregated output from the set of triggered rules.

The max-min method involves truncating the consequent membership function of each fired rule at the minimum membership value of all the antecedents. A final aggregated membership function is achieved by taking the union of all the truncated consequent membership functions of the fired rules. For the DG unit placement problem, the resulting DG unit suitability membership function μd of node i for k fired rules are given by

$M_d(i)\max[\min[\mu_p(i), \mu_v(i)]]$ where $\mu_p(i)$ and $\mu_v(i)$ are the membership functions of the power loss index and voltage respectively.

After calculating the suitability membership function, it is to be defuzzified in order to determine the node suitability ranking. the centroid method of defuzzification is used.

4. DETERMINATION OF OPTIMUM SIZES OF THE DG UNITS

Size of the DG unit purely operated at upf

Considering a single source distribution system with ‘n’ branches .Let a DG be placed at bus ‘m’ and ‘β’ be a set of branches connected between the source and DG unit buses. If the DG unit is placed bus ‘x’ the ‘β’ consists of branches x1, x2, xn. The DG unit supplies real component of current I_a and for radial network it changes only the active component of current of branch set ‘β’. The current of other branches is not affected by the DG unit.The new active component of current

$$I_{ai}^{new} = I_{ai} + D_i I_{DG} \qquad (3)$$

Di =1 if branch iε β
=0 otherwise.

I_{ai} is the active component of current of ith branch in the original system obtained from the load flow solution.

The loss P_{La}^{com} is associated with the active component of branch currents in the compensated system.

For a DG unit (upf) placed at node ‘k’, the system losses are

$$P^{Com} = \sum_{i=1}^{k} (I_{ai} + D_i I_{DG})^2 R_i + \sum_{k+1}^{n} I_{ai}^2 R_i + \sum_{i=1}^{n} I_{ri}^2 R_i \qquad (4)$$

I_{DG} is the DG unit current

Subtracting Eqn. (4) from Eqn. (2), loss reduction due to the introduction of DG unit at node ‘k’ is obtained.

$$\Delta P_k = -2 I_{DG} \sum_{i=1}^{k} D_i I_{ai} R_i - I_{DG}^2 \sum_{i=1}^{k} D_i R_i \qquad (5)$$

Assuming no significant change in the node voltage after placing the DG unit

Power that can be generated at upf is

$$P_{DG} = I_{DG} V_k \qquad (6)$$

The idea is to place a DG unit (upf) with a size and at a location such that the system loss reduction is maximized using Eqn. (5). For system loss reduction to be maximum the DG unit is to be placed at node ‘k’,

$$\frac{\partial P_k}{\partial I_{DG}} = 0 \qquad (7)$$

$$I_{DG} = -\frac{\sum_{i=1}^{k} D_i I_{ai} R_i}{\sum_{i=1}^{k} D_i R_i} \qquad (8)$$

$$= \frac{\sum_{i\varepsilon\beta} I_{ai} R_i}{\sum_{i\varepsilon\beta} R_i}$$

Substituting Eqn. (8) in Eqn. (6)

The expression for maximum loss reduction is

$$\Delta P_{\max} = \frac{(\sum_{i=1}^{k} D_i I_{ai} R_i)^2}{\sum_{i=1}^{k} D_i R_i} \qquad (9)$$

It is noted that the loss reduction is always positive.

Size of the DG unit operated at any power factor

With the introduction of DG unit 'at any power factor'

$$P^{Com} = \sum_{i=1}^{n} (I_i + D_i I_{DG})^2 R_i + \sum_{i=1}^{n} I_i^2 R_i \quad (10)$$

Subtracting eqn. (10) from (2)

$$\Delta P_k = -2 I_{DG} \sum_{i=1}^{k} D_i I_i R_i - I_{DG}^2 \sum_{i=1}^{k} D_i R_i \quad (11)$$

$$\frac{\partial P_k}{\partial I_{DG}} = 0 \qquad (12)$$

$$S_{DG} = I_{DG} V_k \qquad (13)$$

$$I_{DG} = -\frac{\sum_{i=1}^{k} D_i I_i R_i}{\sum_{i=1}^{k} D_i R_i} \qquad (14)$$

The expression for maximum loss reduction is

$$\Delta S_{\max} = \frac{(\sum_{i=1}^{k} D_i I_i R_i)^2}{\sum_{i=1}^{k} D_i R_i} \qquad (15)$$

The process can be repeated for all the buses to get the highest possible loss saving for a singly located DG unit.

5.1 RADIAL DISTRIBUTION SYSTEM LOAD FLOW ANALYSIS

Conventional load flow studies like Gauss-seidal and fast decoupled load flow and Newton raphson methods are not suitable for distribution system load flows because of high R/X ratio. A new radial load flow method for distribution systems that offers better solution was proposed in [4].

The main features of this method are

1) The initial voltage at all nodes is assumed to be the voltage specified at the source node.
2) No complicated calculations are involved
3) Loads are represented by constant power.
4) Convergence is obtained by, even for ill conditioned system.

5.2. SIMULATION ALGORITHM

There are many computational steps involved in finding the optimal DG size and location to minimize losses in a radial distribution system. These are

1) Run the load flow program. Select the bus where the maximum loss and low voltage is using fuzzy logic tool box. Corresponding DG size is calculated using eqn. (6) and eqn. (13) for DG operated at upf and DG operated at any power factor respectively.
Repeat this for all the buses except the source bus. Identify the bus using the fuzzy logic that provides highest loss saving.
2) Compensate the bus with the highest loss with the corresponding DG unit found from eqn (6) and eqn. (13) respectively.
3) Repeat the steps 1 and 2 to get the next DG size and hence sequence of buses to be compensated.
4) Once the sequence of buses is known determine the optimum DG unit sizes and the corresponding loss saving.

Since the system load is time variant and load duration curve of the system can be approximated .It is assumed that load level is constant. The above algorithm provides the optimal DG sizes and locations for a given load level for DG operated purely at upf and DG operated at any pf.

6. SIMULATION RESULTS

The proposed method of loss reduction by DG unit placement was tested on a

Distribution system consisting of 33 buses. The single line diagram is shown in Fig.1.

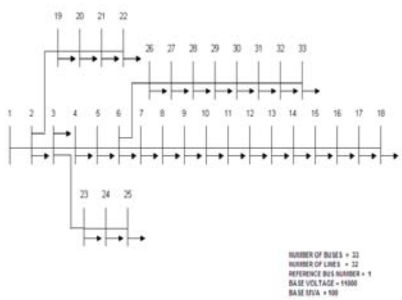

Fig. 1 Single line diagram of IEEE 33-Bus Test System

Optimal sizes of DG units are calculated at each and every bus for case1 with DG at upf and case2 with DG at any pf. Optimal location is obtained using FIS editor. DG unit suitability index greater than 0.75 are selected to place the DG unit. From FIS editor it is found that 26th and 31st buses are the suitable nodes. The ranges of power loss indices and voltage are shown in Table – 1. DG unit suitability membership function details are given in Table – 2.

Table-1. Power loss indices and voltage membership functions.

Description of the variables	Low	Low - Medium	Medium	High-Medium	High
Power loss indices	< 0.25	0-0.5	0.25 - 0.75	0.5-1	0.75 - 1.25
Voltage	< 0.94	0.93 - 0.965	0.96 - 1.04	1.03 - 1.07	1.06 -1.2

Table-2 DG Unit Suitability index membership function.

Description of the variables	Low	Low – Medium	Medium	High-Medium	High
DSI	< 0.25	0-0.5	0.25 - 0.75	0.5-1	≥ 0.75

With the help of FIS editor optimal location of the DG unit is found where real power loss is more and voltage is low. Using analytical method the sizes of the DG unit are obtained and placed at optimal location, power loss and voltage improvement is observed. The optimal sizes of DG units at upf and DG units at any pf are shown in Fig. 2 and 3 respectively. The total loss reduction is minimum at 0.8 power factor. This can be observed from Fig. 4. Voltage variation with and without DG at upf is shown in Fig.5. Voltage variation with and without DG at 0.8 pf are shown in Fig. 6. The results are tabulated for both the cases in Tables 3 and 4.

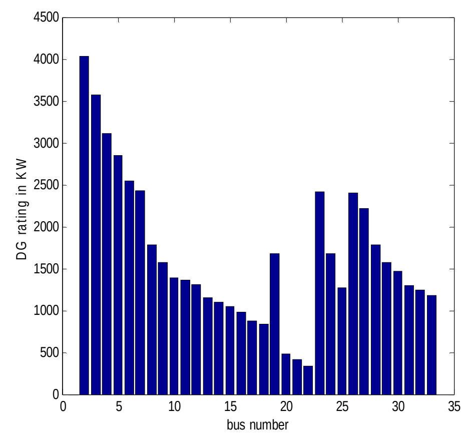

Fig. 2 DG unit sizes purely at upf for 33 bus system

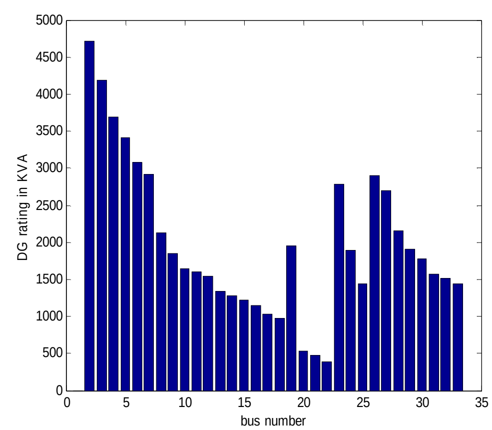

Fig. 3 DG unit sizes operated at any pf for 33 bus system

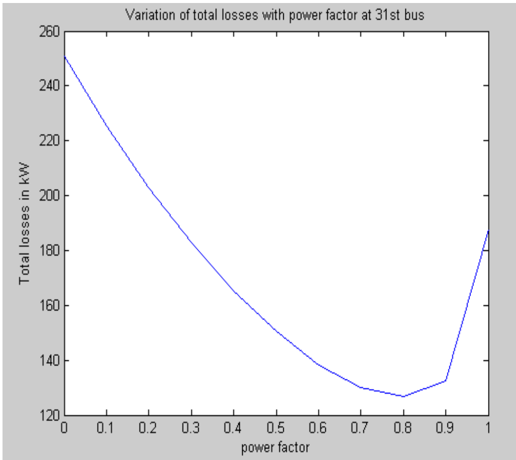

Fig. 4 Variation of total losses with power factor

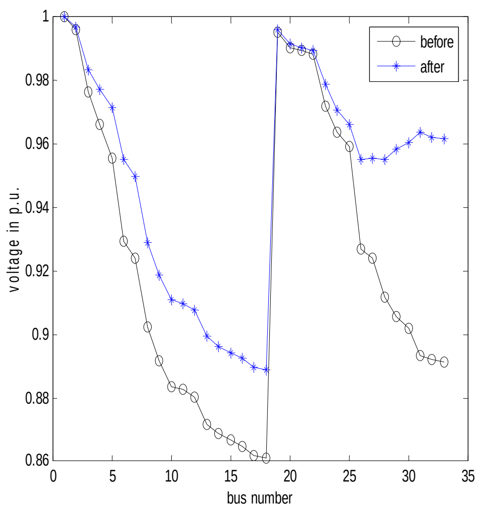

Fig. 5 Voltage variation with and without DG unit (upf) at 31st bus

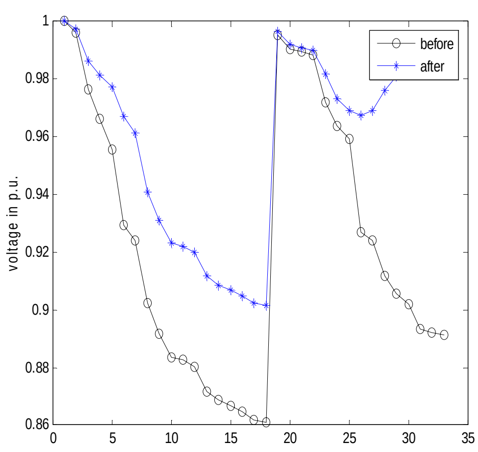

Fig .6 Voltage variation with and without DG unit (0.8pf) at 31st bus

Table – 3 Power loss with DG unit placement 'at upf' using Analytical method

Bus Number	DG Unit Sizes kW	TAPLBC kW	TRPLAC kVAR	TAPLAC kW	TRPLAC kVAR	APLR kW	RPLR kVAR
26	2395.6	289.55	194.25	154.197	110.28	135.35	83.17
31	1290.5	289.55	194.25	185.96	130.7447	103.59	63.50

Table - 4 Power loss with DG unit placement 'at 0.8 pf' using Analytical method

Bus Number	DG Unit Sizes kVA	TAPLBC kW	TRPLAC kVAR	TAPLAC kW	TRPLAC kVAR	APLR kW	RPLR kVAR
26	2908	289.55	194.25	89.5047	69.63	200	124.62
31	1578	289.55	194.25	126.8927	93.3116	162.657	100.93

Table – 5 Summary of the Results using Analytical Method – 33 bus Test System

	with DG 'at upf'				with DG at 0.8 pf			
Bus No	DG Unit Sizes	%APLR	%RPLR	%VI	DG Unit Sizes	%APLR	%RPLR	%VI
26	2395.6	46.74	42.81	5.45	2908	69.07	64.15	7.74
31	1290.5	35.77	32.68	7.84	1578	56.17	51.958	11.359

From the summary of the results shown in Table – 5 one can conclude that there is very good improvement in voltage level and power loss with DG operated at 0.8pf.

CONCLUSIONS

From the results it is observed that DG unit operated at 0.8 power factor is very effective in reducing the total power loss and in improving the voltage profile of the system. It is recommended to operate DG at 0.8 pf to improve the performance of the system.

At 26^{th} bus active power loss reduction is 69% at 0.8 pf compared to DG at upf with 46%.Similarly reactive power loss reduction is 64.15% at 0.8pf compared to DG at upf with 42.81%.Percentage Voltage improvement is 7.7% with Dg at 0.8pf whereas 5.45% with DG at upf

REFERENCES

[1]. H.N.Ng and M.M.A. Salama, "Fuzzy Optimal Capacitor Sizing and Placement *IEEE Canadian Conference on Electrical and Computer Engineering,* vol. 2, *pp.680-*683, 1995.

[2]. H.N. Ng, M.M.A. Salama A.Y. Chikhani, "Capacitor Placement in Distribution Systems Using Fuzzy Technique", *IEEE Canadian Conference on Electrical and Computer Engineering,* vol. 2, pp.790-793, 1996.

[3]. M.H.Haque, "Capacitor placement in radial distribution systems for loss reduction", *IEEE Proc - Gener. Transm. Distrib*., vol. 146,pp.501-505,1999

[4]. S.Ghosh and D.Das , "Method for load-flow solution of radial distribution Networks", *IEE Proc.- Gener. Transm. Distrib*. vol. 146, no. 6, pp. 641-648, 1999.

[5]. H.N.Ng, M.M.A.Salama and A.Y.Chikhani, "Classification capacitor allocation techniques", *IEEE Transactions on Power Delivary*, vol.15, pp.387-392, 2000.

[6]. H.N.Ng, M.M.A.Salama and A.Y.Chikhani, "Capacitor allocation by approximate reasoning: Fuzzy capacitor placement ,"*IEEE Transactions on Power delivary*,Vol. 15, pp.393-398, 2000.

[7]. Griffin. T, Tomsovic, K, Secrest, D and Law, A, "Placement of dispersed generations systems for reduced losses", *Proceedings of the 33rd Annual Hawaii International Conference on system sciences,* pp.1446 –1454, 2000

[8]. Fernando L. Alvarado, "Locational aspects of Distributed generation", *IEEE/PES Winter Meeting*, vol.1pp.140, 2001.

[9]. Thomas Ackermann and Valery Knyazkin, "Interaction between Distributed Generation and the Distribution Network: Operation Aspects", IEEE Transmission and Distribution Conference and Exhibition, pp.1357-362, 2002.

[10]. CELLI, G. and PILO, F.: "Optimal distributed generation allocation in MV distribution networks", *IEEE PES Intl. Conf. on Power Industry Computer*

[11]. MASTERS, C.L., "Voltage rise: the big issue when connecting embedded generation to long 11kV overhead lines", *Power Engineering Journal*., 16 (1), pp. 5-12, 2002.

[12]. Kyu-Ho Kim, Member, Yu-Jeong Lee, Sang-Bong Rhee, Sang-Kuen Lee and Seok Ku You, "Dispersed generator placement using fuzzy-GA in distribution systems", *IEEE Power Engineering Society Summer Meeting,* pp. 1148-1153, 2002.

[13]. R.O' Gorman and M.A.Redfern"Voltage Control Problems on Modern Distribution Systems",

IEEE/PES General Meeting, pp. 662-667, 2004

[14]. Caisheng Wang and M. Hashem Nehrir, "Analytical Approaches for Optimal Placement of Distributed Generation Sources in Power Systems", IEEE Transactions on Power Systems vol. 19, No. 4, pp.2068-2076, 2004

[15]. M.Mardaneh and G.B.Gharehpetian, "Siting and sizing of DG units using GA and OPF based Technique", *IEEE/TENCON,* vol. 30, pp. 331-334, 2004.

[16]. N. Mithulananthan, Than Oo and Le Van Phu, "Distributed Generator Placement in Power Distribution System Using Genetic Algorithm to Reduce Losses", *Thammasat Int. J. Sc. Tech.,* vol. 9, pp.55-62, 2004.

[17]. J.Balakumaran and K.Thanuskodi, "Loss reduction in Radial Distribution systems by Capacitor Placement: Fuzzy Technique", *IEEE/E-Tech*,pp. 23-29, 2004

[18]. N.Acharya, P.Mahat and N.Mithulanathan, "An analytical approach for DG allocation in primary distribution network", *International journal of Electrical power and Energy Systems*, vol. 28, pp.669-678, 2006.

[19]. Mrs. A. Lakshmi Devi and Prof B.Subramanyam, "Optimal Dg Unit Placement For Loss Reduction In Radial Distribution System-A Case Study", ARPN (Asian Research PublishingNetwork)Journal,vol2,No.6,pp.57-61, December 2007.

[20]. Mrs. A. Lakshmi Devi and Prof B.Subramanyam, "A New Hybrid Method For Loss Reduction And Voltage Improvement In Radial Distribution System-A Case Study", i-manager's journal on Electrical Engineering,vol1,No.3,pp.64-68,January-March 2008.

A.Lakshmi Devi.Obtained her B.Tech in 1991 from S.V.University college of engg ,Tirupati and M.E in 1993 from IISC,Bangalore.She is associate professor of Electrical engineering since 1993.Her area of interest are in Distribution systems,Distribued generation and Facts.She is working for her Ph.d work.

B.Subramanyam Obtained his B.Tech in 1968 from S.V.University college of engg ,Tirupati and M.E in 1971 from REC,Warangal. He obtained his Ph.Dfrom REC Warangal in the year 1977.He worked as professor of Electrical engineering in S.V.U.College of Engg,Tirupati till 2005..His area of interest are in Distribution systems,Distribued generation ,Facts, Control systems and instrumentation.