# COMPREHENSIVE LOAD FLOW ANALYSIS WITH DISTRIBUTION ENERGY RESOURCES IN A PRACTICAL INDIAN DISTRIBUTION FEEDER

**Ebuthi Chinna Sunkaiah[1],Dr.B.Muruganantham[2]**

1. Department of Electrical and Electronics Engineering, Gates institute of technology, Gooty, Anantapuaramu-515401, India
2. Department of Electrical and Electronics Engineering, M.A.M. College of Engg. and Tech., Tiruchirappalli – 621 105, India

Email:chinnasunkaiah123@gmail.com, muruganantham.gates@gmail.com

## ABSTRACT

The world is going with latest advanced technologies in various fields and demand for electricity is increasing. The diminishing of possible fuels made world focused on renewable energy resources. The developing countries like India are much of wind and solar potentials. When power is transfer from substation end to distribution feeder power losses and voltage drop occur. This paper is focused on integration of wind and solar energy on a local distribution feeder. After integrating solar in a feeder at a node, node voltage and power is improved during day time. During night time the feeder is integrated with wind, load factor & power quality is improved. The load flow is computed using forward- backward sweep method through *IEEE GRIDLAB-D* software. Voltage and load flow solution improved for better performance of the distribution feeder network.

**Keywords: -**Local Distribution Feeder (LDF), Renewable Energy Resources (RES),Forward- Backward (FBS) Method,

## 1. INTRODUCTION

The power system comprises of generation, transmission and distribution [1]. The distribution system is having residential and industrial system with different operating voltages. The maintenance of load profile is one of the major concerns in the local distribution feeder. The voltage is decreased from substation to local distribution feeder (LDF) due to losses and voltage drop occur with various loads. Each distribution feeder consists of individual distribution feeders and phases, that is three phase & single phase with various voltage ratings and power levels which are not linear and unbalanced, sometimes power on each phase will be different results in voltage drop at nodes and consume more power and does not give satisfaction to the consumers. The most of the consumers are large scale, medium scale and small scale on LDF has various nodes with different loads. For small scale a consumer which has three phase or single phase. Sometimes in between three phases A, B and C a single phase is connected between A&B, B&C or A&C and remaining phases are not connect with load. Because of more loads in one phase, results in more voltage drop and losses causing the system with poor load flow.

The demand of electricity is increasing day by day. This can be fulfilled only with generation of electricity. With usage of fossil fuels, oil, coal and gas, electricity will be generated. But degradation of environment and diminishing of fossil fuels and carbon emission entire world is concentrating towards RES[2].From starting feeder to ending feeder voltage is decreased. A RES is integrated in LDF a voltage profile is increased. When it is integrated with solar energy depends on solar irradiance generates power and voltage at a particular load at which is connected [13, 6]. With more solar irradiance more power will generate causing the system to improve load flow. Sometimes more generated power is send back to grid if it is tied with grid. Here the load flow will be analyzed by using FBS method. The voltage level is improved for all seasons depend on solar irradiance. After integrating with solar energy voltage level, active and reactive power is improved at a particular node on LDF. But load factor is not improved. Load flow solutions will be improved for day time in case of all seasons. While at night time it is same as that of base load conditions. Load flow solutions are not improved due to no solar irradiance during night time. To improve load factor and power flows during night wind energy is connected at substation and implemented for all seasons [3]. When wind module is integrated in the nodes the power flow and load factor improved. The load flow calculation is done with time series analysis through GRIDLABD software[12, 15].

## 2. LOAD FLOW METHODS

To analyze the performance of LDF different load flow methods are used. In the load flow analysis real power, reactive power and voltage at various nodes computed. To compute the load flow solutions various power flow methods such as Newton Rapson (NR), Gauss Seidel (GS), Fast Decoupled Method (FDM) and Forward Backward Sweep (FBS) methods are availed[4,5] But now a day's distribution network is integrated with RES to analyze the load flow methods each and every method has its own advantage and disadvantage depends on type of network configuration [6]. The NR method having more disadvantages in local distribution network (LDN), commonly power flow solutions are computed by iterative techniques. NR requires heavy computational memory. It is not appropriate method for LDN[7]. In case of unbalanced loads it is high R/X ratio. It will take more time to get converging point. This method mainly involves difficult Jacobianmatrix to solve power flow equations.

To determine the load flow solutions without Jacobian matrix for radial distribution network with no losses at initial conditions FBS method is used. In this method no Jacobian matrix method used to compute power flow problems [5]-[6]. Through this method node voltages at each and every node is calculated form end node to start node and vice versa.

## FORWARD BACKWARD SWEEP ANALYSIS

Due to high $R / X$ ratio and Jacobian matrix for distribution network is integrated with RES. Forward backward sweep analysis method is most suitable method to analyze the response of power flow problems. Through this method convergence is achieved by iterative technique [3]. The iteration is completed with forward and backward process. In forward sweep method we are using KVL whereas KCL followed in backward to improve the computational efficiency [7].

In this ladder network it is assumed that all the load and line impedances to be known along with the voltage source.

Consider a distribution network as shown in figure.1

$$VI = S_4$$

Where $S_4$ is taking as a load

In Backward sweep analysis method calculation starting from tail end to source end by applying KCL & KVL. In this method $V_4$, $V_3$, $V_2$, $V_1$is calculated and finally compare with source voltage, if the convergence is achieved otherwise go through forward sweep to achieve convergence [3].

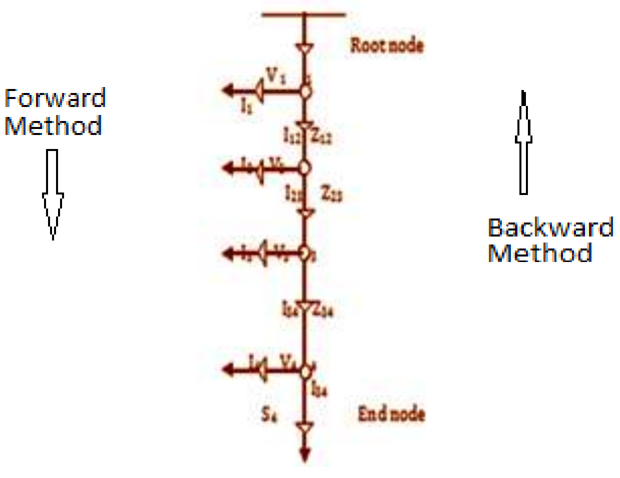


Figure.1. Local distribution network with node voltages and branch currents.

The first iteration computed in FBS method with backward & forward method. Iteration process is repeated until convergence is achieved [2].

The voltage computation through FBS method in Backward Sweep analysis for above LDN is as follows.

$$V I_4 = S_4 \qquad (1)$$

$$I_4 = S_4 / V \qquad (I_{34} = I_4)$$

$$V_3 = V_4 + Z_{34} * I_{34} \quad (I_{23} = I_3 + I_{34}, \quad I_3 = S_3 / V_3)$$

$$V_2 = V_3 + I_{23} * Z_{23} \qquad (2)$$

$$V_1 = V_2 + I_{12} * Z_{12} \qquad (3)$$

The voltage computation through FBS method in forward Sweep analysis for above LDN is as follows.

$$V_2 = V_1 - I_{12} * Z_{12} \quad (I_{23} = I_3 + I_{34}, \quad I_3 = S_3 / V_3)$$

$$V_3 = V_2 - I_{23} * Z_{23} \qquad (4)$$

$$V_4 = V_3 - Z_{34} * I_{34} \qquad (5)$$

$V_4$ is compared with reference voltage. The iteration is repeated until the voltage difference is less than 0.001 i.e. convergence is achieved.

## SOLAR INTEGRATION

Solar systems are seeking more attention as solar potential is omnipresent, and cost of photovoltaic (PV) cell is reducing nowadays. The PV systems are intermittent in nature and cannot satisfy the power requirement throughout the year [16]. The distance from substation is increases, power losses increases in LDF network due to voltage drop and which makes the voltage below its nominal voltage. In this paper IEEE 10 nodes LDF network having voltage drop and power losses occur at various nodes [12]. The voltage profile as well as power flow can be improved by integrating with solar RES at particular node. The power flow is computed by FBS analysis method.

When solar is integrated at particular node, the voltage can be improved for all seasons depend on solar irradiance [14]. By integrating solar at a particular node energy losses are reduced, voltage profile is increased. The power flow and voltage computed by using FBS analysis method. During day time only power flow and voltages improved for all seasons. But voltage decreases during night time. Load factor for entire day decreases and alter the power factor and cause to does not give any satisfaction to consumers by giving more energy bills due to absence of solar irradiance at night time.

## WIND INTEGRATION

To improve the load factor and load flow solutions at night time LDF network is integrating with wind energy. When DN is integrated with solar energy, improves load profile during day time for all seasons due to much availability of solar irradiance but due to absence for night time voltage dip is occurred.

When LDF is integrated with wind energy, based on wind potential it generates more power consequently line and energy losses are reduced at all nodes particularly at night time for all seasons. The improved voltages calculated by using FBS analysis method. Load factor also improved due to increasing generation of electrical energy through wind energy.

## VOLTAGE IMPROVEMENT

As the distance increases the voltage is decreased by integrating solar PV cells at a particular node wherever voltage dip occurred, the voltage and load flows can be improved. Depends on solar irradiance the voltage profile is increased for all seasons during day time only. But load factor is altered. For improvement of load flow solution and load factor for all seasons at night time wind turbine generator is integrated at substation.

When wind turbine is integrated the load factor and voltage profile is increased during day and night time for all seasons at particular node at which dip occurred.

## LOAD FACTOR

Load factor is defined as the ratio of average power consumed over a particular period to the max power for same period of time.

$$\text{Load factor} = \frac{\text{average power consumed}*\text{time}}{\text{peak demand}*\text{time}}$$

The load factor is always less than unity for better performance of local distribution network. It is main consideration factor in the power flow analysis of LDF network after integrating with RES. Load factor is also affecting consumed power of a customer. For a good load factor maximum demand is always nearly equal to the average demand but not exceed maximum or peak demand over a particular period of time.

## 3. PROBLEM FORMULATION METHOD OF FBS

Generally most of distribution networks are Radial DN. Due to more expensive and involving switches and conductors Ring main DN are not preferred.

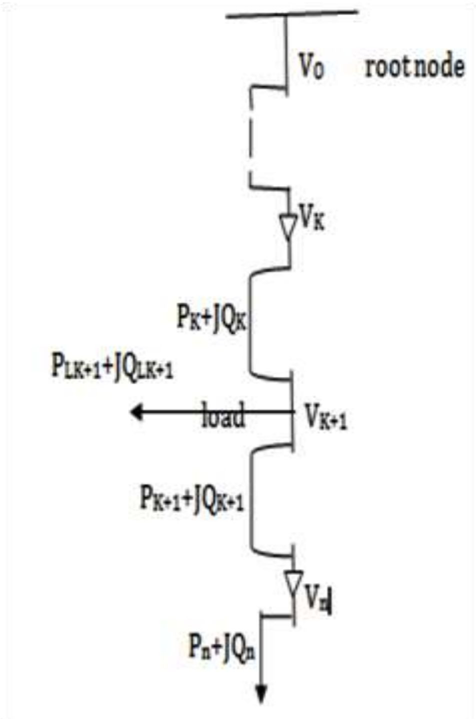


Figure.2. Local distribution network

Fig.2. Illustrate the one line diagram of local distribution network having no of buses with active and reactive power lines.

It is also not suitable for low voltage generation. The power flow in a DN is computed by using lad flow methods[11]. The objective function to find power loss is

$$P_{K+1} = P_K - P_{LOSS,K} - P_{LK+1} \quad (6)$$

$$Q_{K+1} = Q_K - Q_{LOSS,K} - Q_{LK+1} \quad (7)$$

$P_K, Q_K$ are real and reactive power flowing out of bus.

$P_{LK+1}$, $Q_{LK+1}$ are real and reactive load power flowing at bus k+1. The total power loss of feeder is determined by adding the losses of all line sections of feeder.

$$P_{T,LOSSES}(K, K+1) = \sum_{K=1}^{n} P_{LOSSES}(K, K+1) \quad (8)$$

$$Q_{T,LOSSES}(K, K+1) = \sum_{K=1}^{n} Q_{LOSSES}(K, K+1) \quad (9)$$

$$P_{LOSSES}(K, K+1) = R_K \frac{Q_K^2 + P_K^2}{V_K^2},$$

$$Q_{LOSSES}(K, K+1) = X_K \frac{Q_K^2 + P_K^2}{V_K^2}.$$

$P_{LOSSES}(K, K+1)$, $Q_{LOSSES}(K, K+1)$ are losses in line section buses of K and K+1 as shown in figure .2

In FBS method each of iteration has two stages, one is from tail end to root node taken as backward sweep and in other forward sweep method from root node to tail end compute power flow solutions [1,10].The backward system is generally updating current or power flow solutions with impedances by taking load and voltages. The final updated voltage is compare with reference voltage if difference is less, then convergence is achieved

In forward sweep method voltage drop is calculated with computed values from backward sweep method. The iteration is completed after forward and backward sweep method only. This process is repeated for no of iterations till convergence is achieved[7].

Now FBS method is formulated in such a way for analysis of convergence iterative process. Suppose a branch connected between buses K, K+1 with number of feeders and nodes. PK and QK are power flows through feeder between buses K, K+1 can be computed using backward sweep method from end node to root node. The computed power flow equations are

$$P_K = P_{LK+1}^1 + R_K \frac{Q_{K+1}^2 + P_{K+1}^2}{V_{K+1}^2} \quad (10)$$

$$Q_K = Q_{LK+1}^1 + X_K \frac{Q_{K+1}^2 + P_{K+1}^2}{V_{K+1}^2} \quad (11)$$

$P_{LK+1}^1 = P_{K+1} + P_{LK+1}$ , $Q_{LK+1}^1 = Q_{K+1} + Q_{LK+1}$ .

Where $P_{LK+1}$ = loads connected at k + 1 node

$P_{K+1}$ = effective power at k + 1 node

The voltage magnitude and angle are calculated through forward direction and current flowing in branch having impedance $Z_k = R_k + J X_k$ between K and K+1 node is given by

$$I_K = \frac{V_K\angle\delta_K - V_{K+1}\angle\delta_{K+1}}{Rk + J\,Xk} \quad (12)$$

Initially a flat voltage profile is assumed at all nodes. The currents and powers are computed in backward method, voltage and angles are calculated in forward method[3].

## SOLAR PV CELL MODELLING

The solar PV module consist of no of arrays connected either in parallel or series combination which consist of Diodes in series with resistance and current source to Convert the solar energy into electrical energy and produce some photo voltaic current proportional to solar radiation [8,9]. The solar array with inverter type module is shown figure 3.

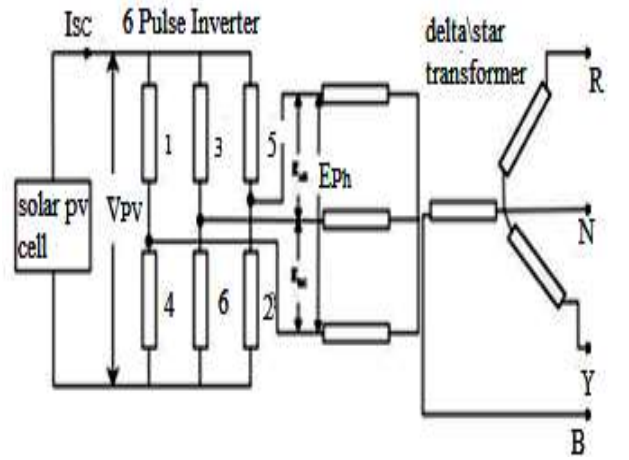


Figure.3.Solar array with inverter type module.

The equation of photovoltaic current is given by

$$I = I_{ph} - I_0[\exp\left(q\frac{(V+IRs)}{AKT}\right) - 1] - \frac{(V+IRs)}{Rsh} \qquad (13)$$

$$I_{ph} = \frac{S}{Sref}(I_{ph,ref} + C_t(T - T_{ref}))$$

$$I_0 = I_{or}(\frac{T}{T_r})^3 \exp\left(\frac{qEg}{K_a}\right)\left[\frac{1}{T_r} - \frac{1}{T}\right] \qquad (14)$$

Where $I_{0r}$ refers the diode saturation current under standard test conditions.
Eg is the energy band of the cell semi-conductor (eV) depending on the material used.

Solar Radiation and cell temperature is given by

$$Iph = [Iscr + ki(T - Tr)]\ S/K \qquad (15)$$

$$I_{ph} = \left[I_{scr} + K_i\left[\frac{1}{T_r} - \frac{1}{T}\right]\right]\frac{S}{K_0} \qquad (16)$$

Where $K_i$ is the short circuit current temperature co-efficient.

The PV array produce output depends on solar irradiation at normal temp 28°c with solar insulation 100 km/cm$^3$ it produce 250 kw at 394 v.

## WIND GENERATOR MODELLING

The wind turbine generator is modelled as a PQ bus assuming system real power, power factor and reactive power consumed is calculated. It is operated with either fixed speed or variable speed induction generator directly connected to grid [11]. The generator is controlled through power electronic converter to maintain proper power factor. When wind generator is modelled with induction generator, which is connected through a gear box to produce maximum rotor speed of the generator. The stator of generator is connected to power electronic converter consist of rectifier, boost converter, 3 Phase pulse width modulated inverter and finally connected to transformer as shown in figure.4.

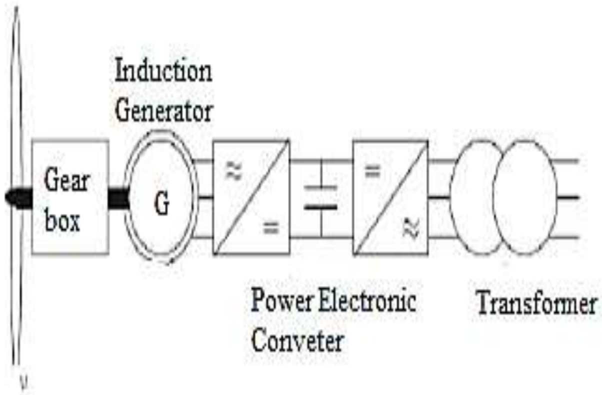


Figure.4.Wind turbine connected with induction type generator.

If the synchronous generator is connected, this is having more number of poles, no need of gearbox as shown in figure .5.

Figure.5. Illustrate the wind turbine generator without gear box indicates more number of poles.

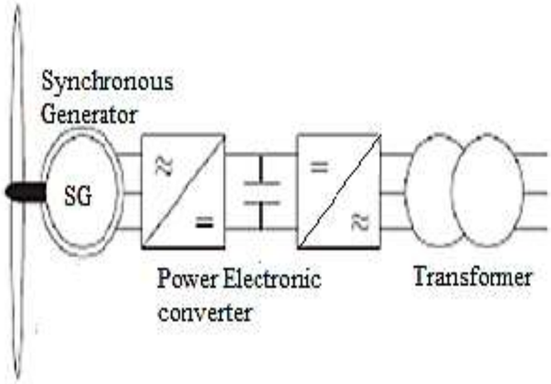


Figure.5. Wind turbine connected with synchronous generator.

The aerodynamic modeling of a wind turbine generator is as shown above and modeling as

The mechanical input power $P_m$ at the shaft is given in (17)

$$P_M = ½\ \rho A(V_W^3)C_P(\gamma) \qquad (17)$$

Where $\rho = 1.25$Kg/m$^3$ is the air density.
A= $\pi r^2$is the area of the rotor.
$V_W$ is the wind velocity.
$C_P(\gamma)$is the aero dynamic power co-efficient.

For a three blade wind turbine the distance of each Blade from the ground as a function of its angular position is given in (18)

$$H_i = H_{hub} + CR\sin Ø \qquad (18)$$

Where i = 1…3

$H_{hub}$ is the hub height.

C < 1 which defines the distance of aerodynamic center of the blade from its root is less than one.

$$V_W(\varnothing,T) = V_W(T)\frac{Hhub + CRsin\varnothing}{Hhub}f(\varnothing) \qquad (19)$$

The total input mechanical power on the shaft is given in

$$P_M = ½\,\rho A \sum i$$

$$= l^3(V_W(\varnothing,T)^3)\frac{1}{3}C_P(\gamma)$$

Where i = 1…3.

**FLOW CHART**

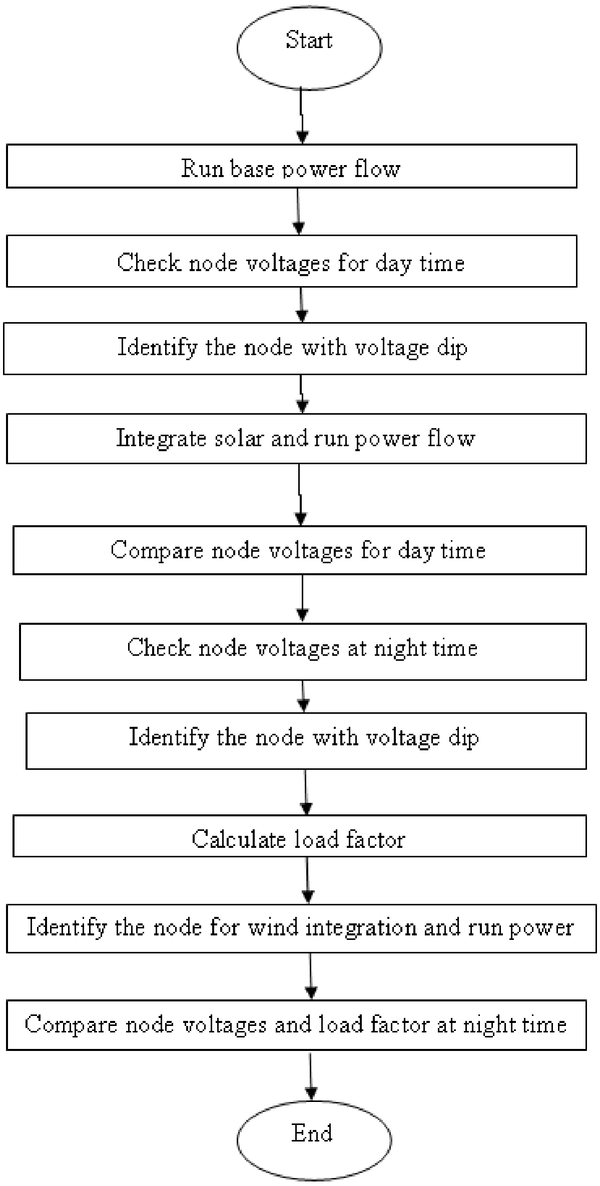


Figure.6. Flow chart for comprehensive load flow analysis of local distribution system.

Figure.6. Illustrate the improvement of load flow analysis for local distribution system with solar and wind distribution system.

**4. RESULTS AND DISCUSSION**

The LDF consists of feeders with different nodes. The active and reactive power and voltage will be different for different nodes based on changing load. The power will change at various nodes, which is different at all nodes due to drop occurred at nodes. The active power and reactive power at any node during any season at day time of a LDF will be altered.

The variation of active and reactive power during day time at node 6 in winter season is as shown in the figure. 7. The active power of the system is always higher than reactive power of the system.

The power will change with respect to time also. The active and reactive power at a particular node during any season at night time of a LDF network is also changed. The active and reactive power is changed at night time with respect to time at any instant.

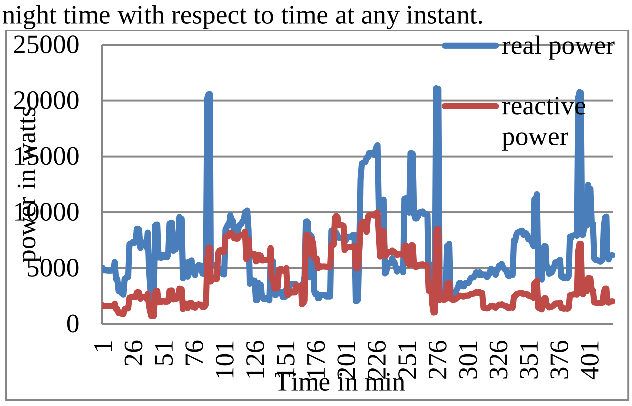


Figure 7 Comparison of active & reactive power for base at day time.

The active and reactive power of the system at node 6 during winter season will changes with respect to time, based on load at night time is as shown in figure.8.

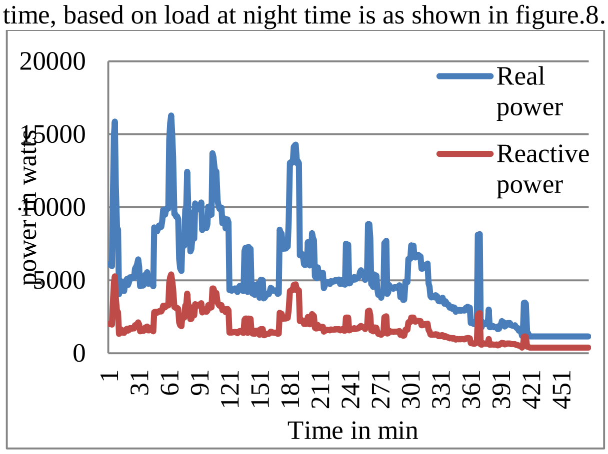


Figure.8 Comparison of active and reactive power at night time for base.

In this paper the voltage dip occurred when the distance from the substation is increases, the voltage drop is more at different node for base case. The voltage at all nodes for winter season at any instant during night time for base case will be decreases due to drop

Figure.9. Illustrate the voltage at all nodes in LDF during winter season in day time. Among all nodes at node 6 more voltage drop occurred followed by node 10.

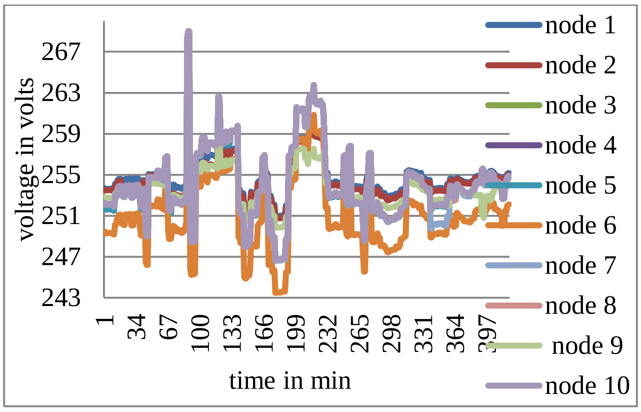


Figure.9. Voltages at day time in winter season at all nodes for base.

As the distance from the LDF increases the voltage drop will be more. To increase the voltage at particular node solar PV cell is integrated in LDF network. After solar is integrating the voltage is improved at day time only due to availability of solar irradiance. The voltage is improved depends on solar irradiance but its improvement is different for all seasons.

Figure.10. illustrates the voltage improvement for winter season at node 6 during day time at all instants. As the time increases based on solar irradiance voltage is improved at node 6 for any season.

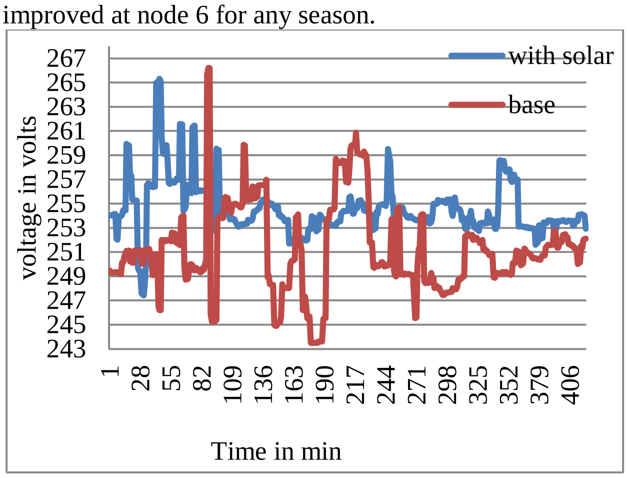


Figure.10. Voltage improved at day time during winter season at node 6.

After integrating with solar due to less irradiance, voltage is not increased properly at night time for all seasons at various nodes. In this paper at node 9 in a local distribution feeder the voltage dip occur.

Figure.11. illustrate the voltage dip occurred during night time at node 9 during night when compared to all nodes on a local distribution feeder network after solar integration.

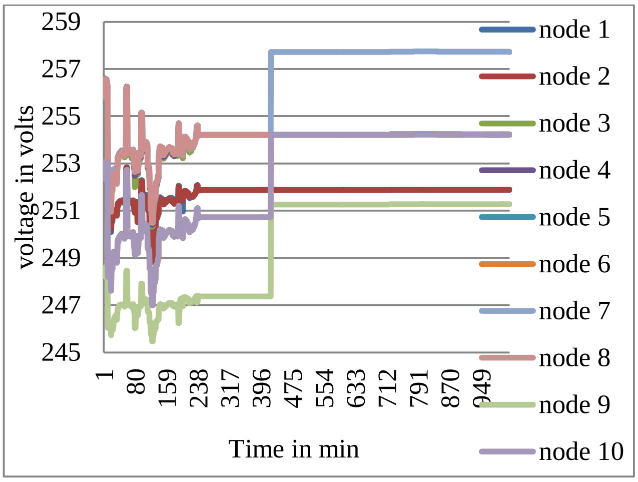


Figure.11 Voltages at night time with solar integration at all nodes

The main drawback of the solar integration is at night time solar irradiance is very less it can improve voltage during day time based on solar irradiance for all seasons. Due to which load factor is also reduced. During day time voltage at all nodes improved. The load factor is calculated for a particular period of time. When integrated with solar, the generation is only day time which causes to decrease the load factor for full day.

The variations of load factor during winter season with respect to all nodes for any season depend on time. This is always computed as the ratio of average power consumed to the total power for entire day. The load factor which mainly affects the power at stage of consumers which cause more power consumed as normal power. At node 9 load factor dip is occurred during winter after feeder is integrating with solar is as shown in above in figure.12.Among all nodes of a local distribution system with solar integration at node 9 voltage dip is occurred for winter season.

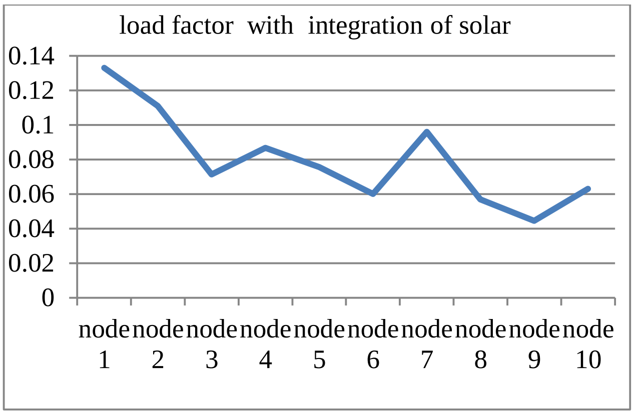


Figure.12. Load factor at all nodes after solar is integrated.

Voltage also improved at night time when integrating with wind at node 9 at night time for any season. After integrating with wind, voltage as well as load factor also increases in a LDF at node 9 where more dip is there. On the bases of wind and solar integration at nodes where more dip is occurred is improved during entire day for all seasons. The voltage improvement at node 9 for winter season with respect to time after wind is integrated at node 9 the voltage is improved for all nodes. But mainly it improves at a particular where it is integrated. In this paper wind is integrated at node 9 to improve voltage due to more voltage drop is as shown in figure13.

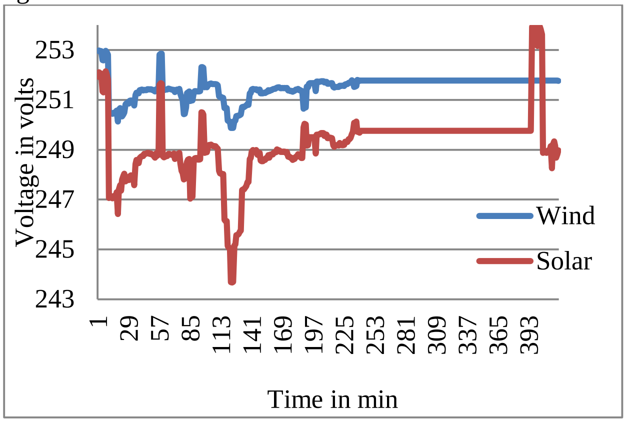


Figure.13 comparison of voltage of wind & solar at night time

Among all nodes of LDF after wind is integrated at node 9 load factor and voltage is improved at particular instant during winter season is shown in below figure.14. The load factor at node 9 and node 7 is improved. Figure.14. illustrate the comparison of load factor of wind energy with solar energy at node 9 in winter season with respect to time.

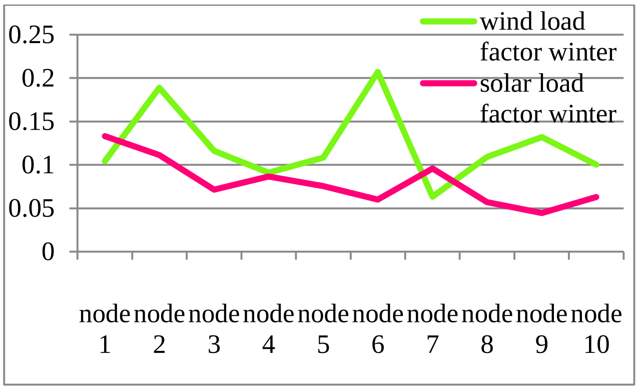


Figure.14 comparison of load factor of solar and wind in winter season.

In this paper the load flow analysis is improved comprehensively with integration of renewable energy sources such as both solar and wind for all season at particular dip node. The load flow analysis is by using FBS method with time series analysis.

**5. CONCLUSION**

In this paper the voltage drop at a particular node in a feeder is identified and impact of solar PV cell and wind energy with a practical distribution system is presented. The time series analysis is provided behavior of the integrated system. The load flow solution is run through forward backward sweep method for all seasons during day and night time by using GRIDLAB-D open source simulation software. Depends on solution voltage dip at node 6 is identified for all seasons and solar is integrated at dip node. Due to impact of solar integration the voltage is increased at day time only. Due to the absence of solar irradiance at night time voltage dip and load factor dip node is identified and wind is integrated. This improves voltage and load factor at night time. This paper explains impact of solar and wind in time domain analysis for distribution system with changing load for all seasons.

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