## 3. Approach

Different cases for Radial distribution feeder are considered like:

1. A radial system prior to the inception of DG into it.
2. A radial system after the inception of DG into it.
3. A radial system with inception of DG and effective distributed storage system.

The above three cases are diagrammatically shown below.

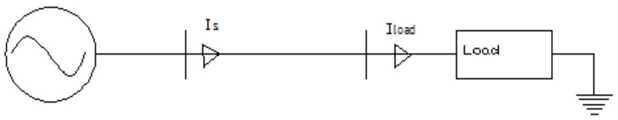


**Figure 1:** A radial system prior to the inception of DG into it.

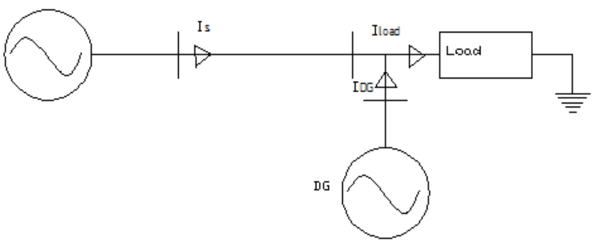


**Figure 2:** A radial system after the inception of DG into it.

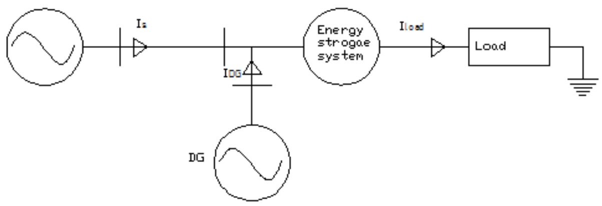


**Figure 3:** A radial system with inception of DG and effective distributed storage system.

Before starting analysis, the following suppositions are made:

1. Loads on both the system are Y- connected, so that line and phase currents are equal ($I_{Line} = I_{phase}$).
2. Load consumes active power at certain specified Power factor.
3. DG generates active power at certain specified power factor.
4. $V_{load}$ is the phase voltage.
5. $V_{load}$ is the Phasor chosen as a reference ($V_{load} \angle 0^0$).

The complex power, [6]

$$S_{load} = P_{Load} + jQ_{load}$$

So

$$I_{Load} = \frac{S^*_{Load}}{3V_{Load}} = \frac{P_{Load} - jQ_{Load}}{3V_{Load}} \; eq(1)$$

## 4. Analysis for Line Loss Reduction

**1: A radial system prior to the inception of DG into it. (Figure1)**

As $V_L = \sqrt{3}V_{Ph}$

$Loss_{BDG} = I^2_{Load}R$

From eq (1)

$$= \left(\frac{|S^*_{Load}|}{\sqrt{3}V_{Load}}\right)^2 rL \;\; \therefore R = rL$$

$$= \left(\frac{|S^*_{Load}|^2}{3V^2_{Load}}\right) \; R \; eq(2)$$

**2: A radial system after the inception of DG into it. (Figure 2)**

Power supplied by DG is given by:

$$S_{DG} = P_{DG} + jQ_{DG}$$

$$I_{DG} = \frac{S^*_{DG}}{3V_{Load}} = \frac{P_{DG} - jQ_{DG}}{3V_{Load}} eq(3)$$

Now for Line losses due from Source to DG is given by:

$$I_S = I_{Load} - I_{DG}$$

Now

$$S = S_{Load} - S_{DG}$$

So,

$$LOSS_{SDG} = \left(\frac{|S^*|}{\sqrt{3}\,V_{Load}}\right)^2 rG = rG\,\frac{(S^*_{Load} - S^*_{DG})^2}{3\,V^2_{Load}}$$

$$= \frac{rG(\,|P_{Load} - jQ_{Load} - (\,P_{DG} - jQ_{DG})|)^2}{3\,V^2_{Load}}$$

After simplification,

$Loss_{SDG}$

$$= \frac{rG(P^2_{load} + P^2_{DG} - 2P_{Load}P_{DG} + Q^2_{load} + Q^2_{DG} - 2Q_{Load}Q_{DG}}{3V^2_{Load}}$$

Now Loss after DG is given by

$$Loss_{DGL} = \frac{(L-G)r(P^2_{Load} + Q^2_{Load})}{3V^2_{Load}}$$

So total losses from source to load is:

$$Loss_{ASDG} = Loss_{SDG} + Loss_{DGL}$$

Putting values the result become as:

$$Loss_{ASDG} = \frac{rL}{3V^2_{Load}}\left[\frac{G}{L}(P^2_{Load} + Q^2_{Load} - 2P_{Load}P_{DG} + P^2_{DG} + Q^2_{DG} - 2Q_{Load}Q_{DG})\right]$$

Where rL=Total Resistance, R so

$$Loss_{ASDG} = \frac{R}{3V^2_{Load}}\left[\frac{G}{L}(P^2_{Load} + Q^2_{Load} - 2P_{Load}P_{DG} + P^2_{DG} + Q^2_{DG} - 2Q_{Load}Q_{DG})\right]$$

Now Line loss reduction after the inception of DG is :

$$LLR = Loss_{BDG} - Loss_{ASDG}$$

So putting values,

$$LLR = \frac{RG}{3LV^2_{Load}}(2P_{Load}P_{DG} - P^2_{DG} - Q^2_{DG} + 2Q_{Load}Q_{DG})eq(4)$$

Now if LLR value is Positive, Line loss decreases after the inception of the DG into the radial Distribution system. If LLR value is negative than line loss will increase after the inception of the DG in the Radial feeder system.

Now Per Unit Line loss Reduction (PULLR) is given by

$$PULLR = \frac{LLR}{Loss_{BDG}}$$

So after simplification

$$PULLR = \frac{G(2P_{Load}P_{DG} - P_{DG}^2 - Q_{DG}^2 + 2Q_{Load}Q_{DG})}{L(P_{Load}^2 + Q_{Load}^2)} \quad eq(5)$$

Percentage LLR is

$$\%LLR = PULLR * 100$$

Now the reactive component of load along with pf is given as:

$$Q_{Load} = \frac{(-1)^n P_{load}\sqrt{1 - PF_{Load}^2}}{PF_{Load}} \quad eq(6)$$

Where n = 1 for load having leading power factor
= 2 for load having lagging power factor

If $Q_{load}$ is positive, load is inductive which absorb reactive power, and $Q_{load}$ is negative, load is capacitive which supply reactive power back to supply.

Consideration of DG operation with leading and lagging power factor:

$$Q_{DG} = \frac{(-1)^n P_{DG}\sqrt{1 - PF_{DG}^2}}{PF_{DG}} \quad eq(7)$$

Where n = 1 for load having leading power factor
= 2 for load having lagging power factor

Now if QDG is positive than it means that DG supplying power to the system and vice versa.

Now combined there are possible four cases in which the conventional power system with the inception of DG along with the load w.r.t power factor is divided as:

1. When both, Load and DG having lagging P.f.
2. When both, Load and DG having Leading P.f.
3. When the load having Leading Power factor and DG having lagging power factor.
4. When the load having lagging Power factor and DG having Leading power factor.

Now as the case 1 and 2, and case 3 and 4 yielding same results. So PULLR values for Case 1 and case 2 are given by:

$$PULLR = \frac{YG(P.f)_{Load}^2}{L}\left[2 - \frac{Y}{(P.f)_{DG}^2} + \frac{2\sqrt{1 - PF_{Load}^2}\sqrt{1 - PF_{DG}^2}}{(P.f)_{Load}^2 * (P.f)_{DG}^2}\right] \quad eq(8)$$

And similarly for case 3 and case 4

$$PULLR = \frac{YG(P.f)_{Load}^2}{L}\left[2 - \frac{Y}{(P.f)_{DG}^2} - \frac{2\sqrt{1 - PF_{Load}^2}\sqrt{1 - PF_{DG}^2}}{(P.f)_{Load}^2 * (P.f)_{DG}^2}\right] \quad eq(9)$$

**3: A radial distribution system with the inception of DG along with effective distribution storage system (Figure 3)**

In this case the system losses are often express as a fraction of the system of load in terms of percent's of demand or percent of delivered energy. Now the ratio of total saved system loss to the peak load can be expressed by:

$$\frac{LLR}{P_{Load_{max}}} = \propto K \frac{2\left(\left(1 - H\left({}^{d}/_{\eta}\right)\right) - \propto\left(1 + {}^{d}/_{\eta}\right)\right)}{1 + H^2\left({}^{d}/_{\eta}\right)}$$

$$= \frac{{}^{I_{st}}/_{I_{Load_{max}}} * 2K\left(1 - {}^{I_0}/_{I_{Load_{max}}}\left({}^{R_o}/_{\eta R_p}\right) - {}^{I_{st}}/_{I_{Load_{max}}}\left(1 - {}^{R_o}/_{\eta R_p}\right)\right)}{1 + \left({}^{I_0}/_{I_{Load_{max}}}\right)^2 {}^{R_o}/_{\eta R_p}} \quad eq(10)$$

Where H = ${}^{I_0}/_{I_{Load_{max}}}$

$$\propto = {}^{I_{st}}/_{I_{Load_{max}}}$$

For each system configuration and load characteristics there is a maximum storage size of the DR when the losses due to charging equal to the reduced system losses with DR. This size is the function of location and ratio of the peak to off peak load. The result has been from analyzing actual load flow simulation, but general equation can be used for an approximation of maximum storage size.

$$\frac{Max_{SS}}{Gap_{Pop}} = \frac{1 - {}^{I_0}/_{I_{Load_{max}}}\left({}^{R_o}/_{\eta R_p}\right)}{\left(1 - {}^{I_0}/_{I_{Load_{max}}}\right)\left(1 - {}^{R_o}/_{\eta R_p}\right)} \quad eq(11)$$

Now saved losses can be expresses as a function of storage size as

$$\frac{LLR}{Storage\ \text{size}} = K\frac{2\left(1-{}^{I_0}\!/_{I_{Load_{max}}}\right)\left({}^{R_o}\!/_{\eta R_p}\right)-\alpha\left(1+{}^{R_o}\!/_{\eta R_p}\right)}{1+\left({}^{I_0}\!/_{I_{Load_{max}}}\right)^2\left({}^{R_o}\!/_{\eta R_p}\right)} \quad \text{eq}(12)$$

From eq(12) it is clear that the ratio of LLR to storage size is dependent on the efficiency of the storage system. But also the size of the energy storage system also affects this ratio too much. If size of the storage device is same as load than LLR to Storage size ratio will maximum while if it capacity is increased than the ratio will decreased.

## 5. Results of Line Loss Reduction

The impact of changing size, location and Power factor of the DG along with the Distributive storage system is studied in this section of the paper. There are four different types of analysis are carried out which are discussed below:

**1. Effect of DG size on the line loss reduction.**

For this purpose to see the relationship between DG size and line loss reduction,it is considered that the DG and Load have same power factor i.e. 0.9 Lagging and the location of the DG is kept at the mid-way between the source and load i.e. G=0.5L where L is assumed to be 1.Load value is assumes as 2pu. PULLR for the above mention value from eq(8) in simplified form is given below:

$$PULLR = -0.125P_{DG}^2 + 0.52P_{DG}$$

and plotted for $P_{DG}$ = [ 0 : 0.2 : 5 ]

Now from Figure4 it is clear that $P_{DG}$ (output of DG) play very important role in LLR of the radial distribution feeder. As $P_{DG}$ output increases up to the $P_{Load}$ (2pu), the LLR become maximum because power from the supply is reduced. When the value of $P_{DG}$ is further increased the LLR is decreasing and reached to zero when the PDG is double the $P_{Load}$. Further increased in the PDG value cause the LLR negative which shows that the DG is supplying power back to the Source through the radial feeder due to which losses is increased. Similarly instead of One DG, more than one DG can be used for N-1 contingency in the system. As a result of which the Reliability and LLR of the system is increased.

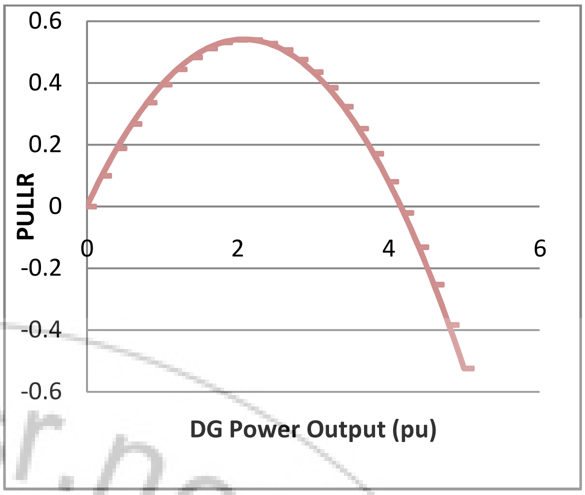


**Figure 4:** Effect of DG power Output on PULLR

**2. Effect of DG location on the line loss reduction.**

For this purpose to see the relationship between DG location and LLR different locations are selected for the DG on the radial Distribution Feeder. For this purpose different values of G are selected i.e. 0(Location 1), 0.2(Location 2), 0.4(Location 3), 0.6(Location 4) and 0.8(Location 5) on the length of the feeder. From eq(8) simplified formulas is given as:

$PULLR = -0.25GP_{DG}^2 + 1.045GP_{DG}$ and plotted for each value of G and $P_{DG}$ = [0:0.2:5].

Now from the analysis Figure5, it is clear that location of DG play very important role in LLR as shown in Figure5. From First and second analysis it is clear that Location and size (DG output) plays very important in LLR. So proper size and location of DG is required for maximum LLR.

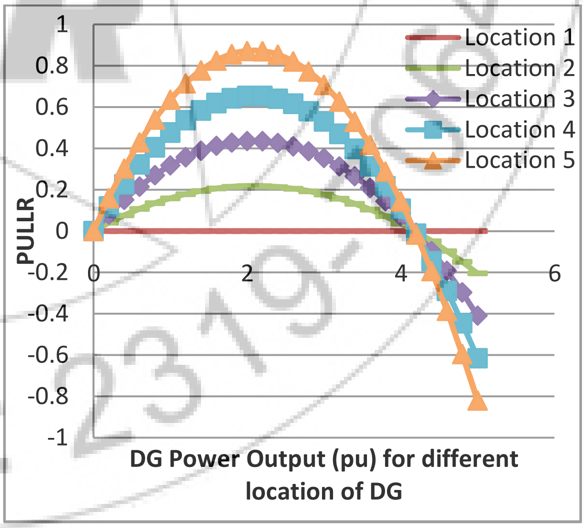


**Figure 5:** Effect of DG power Output on PULLR for different location of DG

**3. Effect of DG Power factor on LLR.**

As power factor of DG may be leading or lagging in nature. From eq(8) the 0.9 lagging power factor DG then $PULLR = -0.125P_{DG}^2 + 0.52P_{DG}$ . Similarly for 0.9 leading power factor eq(9) become as$PULLR =$

$-0.1134P_{DG}^2 + 0.288P_{DG}$ and plotted for $P_{DG}$ = [ 0 : 0.2 : 5 ].

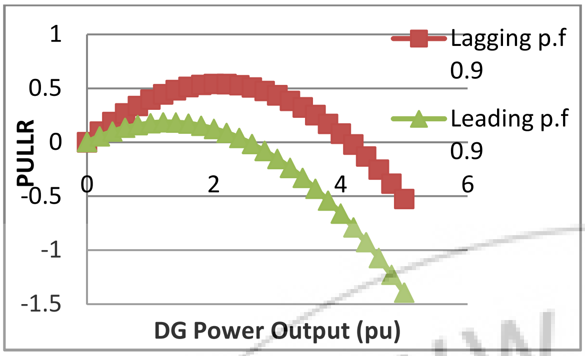


**Figure 6:** Effect of DG Power factor on PULLR

So from Figure6 it is clear that LLR is more for lagging power factor compare with the leading power factor. It is because of the fact that DG also plays its role in delivering reactive power to load. So when DG is operating at lagging power factor, line current is decreases thereby causing LLR.

### 4. Effect of Storage device on LLR.

If the distributive storage system is placed before load, then the LLR is increased or almost remain constant. When the load values are changed from the selected value for which the $P_{DG}$ installed due to which variable load. So if load decreases for the specific values of DG power output then Distributive Storage System will store the extra energy in order to keep the LLR at maximum value for maximum time. Similarly when the load increase then the extra power will be supplied by the energy storage system. From this LLR along with the flattening of the load curve will be obtained. The role of the storage device efficiency is of utmost important parameter for the LLR. If efficiency is 100% or lossless then the LLR to Storage ratio will be maximum. Similarly if the storage device place near the load then the losses further decreased.

## 6. Conclusion

As integration of DG with radial Distribution feeder have many advantages like Line loss reduction, Voltage support, Peak shaving, efficiency of Power system etc. Different DG Technologies are used now-a-day. In this paper, inclusion of DG along with EESS is used for the purpose of LLR for Radial distribution feeder. The analysis clearly reveals that inclusion of DG can really reduce the line losses which are too much advantageous for the Distribution companies in developing countries like Pakistan etc. From analysis it is clear that size, Location and Power factor of DG output are the responsible parameter for maximum LLR during design. If DG is located near the load, then it is not guarantee to maximize the LLR. For increasing the reliability of the power supply to the load as well as LLR, more than one DG is used. For variable load, EESS is put due to which the LLR is increased or almost remain constant. Different energy storage systems are there like pumping of water during off-peak, Batteries etc.

Cost of DG is one of the most important parameter which not allows freely using the available DG technologies but in future, advancement in technologies can reduced cost.

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