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Reduction of Power Loss in Transmission and Distribution Lines by Respect of Comprehensive Planning in Combination with DG Installations Close to Consumers in Rwanda

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Abstract: Transmission and distribution lines, either overhead or underground, are characterized by three parameters: resistance, inductance and capacitance. Unavoidable power losses in the power lines are directly proportional to the aforementioned parameters. The current paper studies the installation of distributed generation (DG) sources close to consumers aiming at shortening the trajectory of electrical power, from generation site to consumption area, resulting into important reduction of loss in power lines. Master plans available in the country will help power line designers to allocate DGs or imported electric power where big consumers are concentrated. Simulation results with power world simulator software show the location of DG with minimum power loss in transmission and distribution lines.

Keywords: Line Loss, Distributed Generation, Comprehensive Planning, Grid

1. Introduction

Power losses appear in line due to many factors in process of transporting electrical energy, from the source to the customers. The power losses caused by current flowing through the series resistance and reactance of the line are dominating. When the line is very long, the line parameters (series resistance and reactance) are high, and the losses are considerably high. Reducing the distance between the power generation and the consumers is one method to limit power loss at minimum level. This can be achieved by: (i) installing DGs near the consumers (or close to the load), (ii) acquiring the imported power at bus bars that are close to higher consumers, (iii) designing power network based on available master plans. Installation of distributed generators would be the first choice as they provide lower-cost electricity and higher power reliability and higher security with fewer environmental problems [1]. Comprehensive planning, that consists of providing master plans, is a complement of the previous choice; its role is to point out the critical regions that require imperative distribution of electricity. The implementation of the current project promises to get power losses less that 23%, an amount of losses estimated in the Rwandan power system in 2014 [2].

Distributed generation (DG) generally refers to small-scale electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system [3]. It is designed to produce active power [4].

The definition of the location of the distributed generation plants varies among different authors. Most authors define the location of DG at the distribution side of the network, some authors also include the customers' side, and some events include the transmission side of the network [5].

Among the types of distribution generation, there are Wind; Photovoltaic (solar); Small-scale hydro; Reciprocating engines; Gas turbines; Fuel cell; Biogas; Phosphorus fuel [6], etc.

2. Electricity Status in Rwanda

2.1. Status of Distributed Generation in Rwanda

Referring to definition of DG, many hydropower plants in Rwanda would be considered as DG types, however they are used as conventional power plants, synchronized together and connected on one network. This bumps the power loss up into the lines linking consumers to generation sites. DGs are being used, but at insignificant rates. They are mostly used as stand-alone backup power sources in domestic and commercial areas on one hand, or in remote areas where the access to electricity from national power network is impossible or is very expensive on the other hand. The available DGs sources in Rwanda are dominated by solar energy, Small-scale hydropower, Biogas. Feasibility studies are under progress aiming at generating electricity from wind and geothermal energy sources available inside the country.

2.2. Importation of Electricity in Rwanda

Rwanda Energy Group (REG), Public company in charge of generating, transporting and distributing electricity is importing power from DRC and Uganda. The power is received in western (Rusizi) and Northern Provinces respectively. There is also a project of importing power from Ethiopia. The total imported power is sent directly to power control center (Gikondo-Kigali) via110kV transmission network. Long transmission lines with low level transmission voltage have consequence of loss augmentation into Rwandan power network.

3. DG location and Its Impact on Power Losses

3.1. Loss Calculation

Line losses are defined as amount of energy converted to any unwanted form of energy. In transmission and distribution lines, these losses occur due to the conversion of electricity to heat and electromagnetic energy [6]. Line losses may be any of three types: (i) Copper, (ii) Dielectric, (iii) Radiation or induction losses [7]. We limit our study on copper losses.

Whenever current flows through one of these conductors, some energy is dissipated in the form of heat. This heat is caused by a power loss which is calculated using the equation below:

$$P_{loss} = R \times I^2 \ \ [Watts] \tag{1}$$

The following factors increase the resistance R of power line conductors; as a result, power loss is boosted.

i) *Skin effect*

With skin effect, the electrical charges are not uniformly distributed into the whole cross-sectional area of conductor, the electrical charges tend to flee the center and occupy the outer part of conductor. This reduces the useful cross-sectional area of conductor, consequently, its resistance increases [8].

ii) *Temperature*

The temperature increases the resistance according to the following equation:

$$R = R_{20^oC} \times (1 + \alpha(\mathrm{T} - \mathrm{T_{ref}})[\Omega] \tag{2}$$

Where

R= Conductor resistance at temperature "T", R_{20^oC} = conductor resistance at reference temperature Tref= 0ºC, α =Temperature coefficient of resistance for the conductor material

iii) *Line length*

The resistance changes with the variation of line length follows

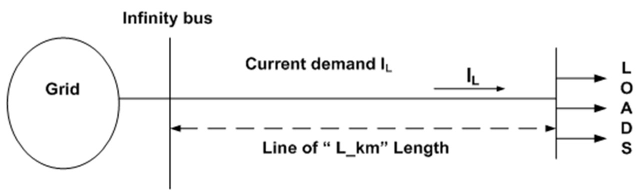
$$R = \frac{\rho}{t} \times \frac{l}{w} [\Omega] \tag{3}$$

Where ρ = resistivity, t = thickness in meter, *l* = conductor length in meter, w = conductor width in meter.

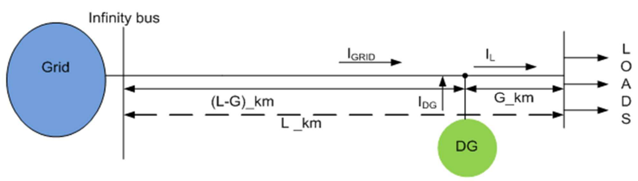
3.2. Impact Distributed Generation to the Line Loss

The magnitude of the loss depends on transmission parameters such as current flow and the line impedance. More the aforementioned parameters are at minimum values, more the power losses are minimized. The use of DGs to provide energy locally to the load, line loss is reduced as the distance covered by current demand in network is reduced [9], [10] & [11].

The figures 1(a) & (b) represent the simplified models of network supplying consumer (load) either with a network with or without DGs. Both systems have a concentrated load at the line end. The total length of the line is assumed to be L in km. The Schematics of the two cases are shown in Figure 1 (a) and (b)



(a) Network without DGs



(b) Network without DGs

Figure 1. *Simplified network for simulation.*

For the system with DG, the location of DG is assumed to be at a distance G km from source. The load complex power is

$$S_L = P_L + jQ_L \tag{4}$$

Therefore, the current absorbed by load is

$$I_L = \frac{P_L - jQ_L}{\sqrt{3}U} \quad (5)$$

Line loss equation for a three phase system is defined as

$$P_{loss} = 3 \times r \times L \times I_L^2 = R \times \frac{P_L^2 + Q_L^2}{3U^2} \quad (6)$$

3.3. Line Loss Analysis with DG

The complex power supplied by the DG equals to

$$S_{DG} = P_{DG} + jQ_{DG} \quad (7)$$

Thus, DG output current is given by

$$I_{DG} = \frac{P_{DG} - jQ_{DG}}{\sqrt{3}U} \quad (8)$$

The line loss with the integration of DG is a combination of two parts: the first part comes from source to the location of DG and the second part from DG location to the location of load.

3.4. Line Losses from the Grid to DG Location

From Figure 1 (b), it can be seen that

$$I_{Grid} = I_L - I_{DG} and I_{DG} = I_L - I_{Grid} \quad (9)$$

Power loss after insertion of DG is calculated as follows

$$P_{lossDG} = 3 \times r \times L \times I_{Grid}^2 + r \times G \times (I_{Grid} + I_{DG})^2$$

$$= 3rL(\frac{P_{Grid} - jQ_{Grid}}{\sqrt{3}U})^2 + 3rG(\frac{P_{Grid} - jQ_{Grid}}{\sqrt{3}U} + \frac{P_{DG} - jQ_{DG}}{\sqrt{3}U})^2 \quad (10)$$

Assuming that the DG's output capacity is matching with power demand, therefore, the current demand I_{Grid} can be negligible compared to total load current demand

$$I_{Grid} \lll\ll I_{Load}.$$

$$I_{Grid} = \frac{P_{Grid} - jQ_{Grid}}{\sqrt{3}U} \rightarrow o, \text{ and}$$

$$P_{lossDG} \approx 3rGI_{DG}^2 \approx 3rG\frac{P_{DG}^2 + Q_{DG}^2}{3U^2} \quad (11)$$

More the distance G (from DG to load) is short; more the line losses are minimized.

4. Power Network Design Based on Available Master Plans

Conventional power plants combined with DGs cannot satisfy the electricity demand in Rwanda. The power importation makes economical solution in condition to maintain equality between generation and demand, and then keep power network reliability within acceptable limit. However, if not well designed, this can cause too much power loss. To overcome this challenge, comprehensive planning for different provinces or districts can help to identify the location of concentration of bigger consumers of electricity. This will result into reduction of trajectory of power as well as losses.

5. Simulation and Results

To show how a good quality of power transmission and distribution planning in combination with DGs installation can mitigate the power loss, a simple power network was modeled. The simple modeled and simulated network has 5 busses, two transformers, two generators, one DG with variable output power. The power demand (load) is fixed to a maximum of 2500MW active power and 820MVAr reactive power. The fig. 2 illustrates the network simulated with power world simulator software. Red-colored small rectangles represent circuit breaker, in closed mode. If the color changes to green, see fig. 3, the circuit breaker is open. On the fig. 2 & 3, total active power loss for the whole network is shown.

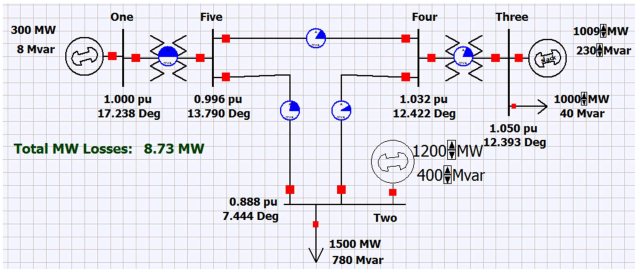


Figure 2. *Network for simulation.*

Table 1. *Variation of power loss versus DG output.*

DG		Gen 1		Gen 2		Loss
P	Q	P	Q	P	Q	
1200	400	300	8	1090	230	8.73
1000	400	300	59	1216	277	16.47
700	400	300	263	1552	517	52.22

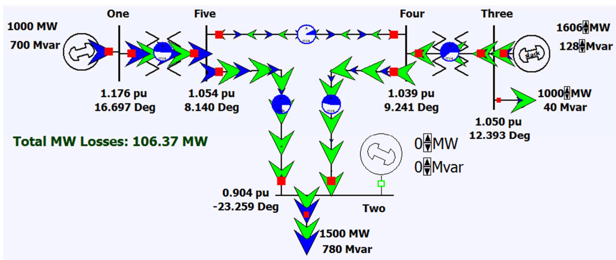


Figure 3. *Simulation with DG deactivated.*

The table 1 illustrates how losses into the network can be minimized by generating near the consumers. When the DG generation capacity is less than the power demand, the generator connected to slack bus is the first to generate and send additional power into the network. The contribution of other generators will depends on missing power generation whereas DG is either at its maximum or minimum (OFF mode) generation capacity, as well as slack generator capacity.

When the DG is turned off as shown in fig. 3, there would be too many losses in lines, or too much stress on lines and transformers.

The circuit breaker between DG and bus two is presented in green color mean that it is OPEN (there is no connection between DG and the bus).

6. Conclusion

As it is shown in the table above, we observe that:

- When DG output is too less than load power, the loss is high because the current pass through the long way from the generator to the load,
- When DG output is proximal equal or equal to the value of the load, the loss is minimized,
- As the DG output is increased more than the load value, the loss is increased because the power that exceed on load demand is inject into the line.

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