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Improving Power Distribution Efficiency On Power Lines

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Abstract

This paper discusses the power factor of transmission and distribution lines for selected power utility substations. The choice of selection of lines was based on the nature of the load and the status of the loading. The data collected and analyzed revealed that some feeder lines at most of substations are distributing active power at low PF below the grid threshold limit. Feeder lines mainly supplying domestic loads have their PF generally low and on the other hand, it was found that feeder lines supplying industrial loads have power factor well above the statutory limit. It is concluded that it is imperative to compensate the reactive current on feeder lines supplying mainly domestic loads in the vicinity of the loads i.e. near the distribution transformers to improve the power factor of these feeder lines in order to increase distribution efficiency and improve the voltage profile.

Keywords: Reactive power, VAr compensator, Power factor, Energy meter, Feeder lines

1. Introduction

Reactive power is a parameter that is associated with power factor that provides the power distribution efficiency and voltage stability of the system on transmission or distribution lines. Most of power quality problems can be mitigated by adequate control of reactive power. It has been proved that reactive power has major correlation with the voltage stability [1]. To minimize the negative effects of low power factor on power distribution on the feeder lines, it is imperative to compensate the reactive power at point of demand. National grid is obliged (Grid code requirements) to secure the transmission network to a closely defined voltage and stability criteria. The reactive power output under steady state conditions should be fully available within the voltage range $\pm$ 5%. This can be achieved through innovative circuit arrangement, transformers on load tap changer, or shunt VAr compensation [2] and [4].
Power factor is an important aspect to consider in an ac circuit. When the power factor (lagging or leading) is less than one it means that the transmission or distribution system has to carry more current than would be necessary with zero reactance in the system to deliver the same amount (real) power to the resistive load [3].

From this work it is concluded that there is need to enhance the existing voltage stabilizing mechanism (on load tap changer) by installing shunt fixed capacitors or variable capacitors depending on reactive power demand. This should be done especially on the feeders and transmission lines supplying domestic loads with substantial loads to improve the power factor and voltage stability.

2. Research Methodology

The data was collected on randomly sampled transmission and distribution lines at selected substations; substations A, B and C . Instantaneous power factor was captured as recorded by energy meters at intervals of four hours each day on different transmission and distribution lines for period of two weeks; one week per month for two consecutive months. For ease of data interpretation and analysis, the data was grouped into highest and lowest instantaneous power factor (IPF) recorded and the time of the day it occurred.

2.1 Criteria for selecting the feeder lines

Feeder lines were selected based on the type of the load (domestic, industrial or mixed) and magnitude of loading (slightly, moderately or heavily loaded). The amount of load was deduced by the maximum active demand (kW) recorded by the energy meter, which determined whether the feeder is slightly, moderate, or heavily loaded.

2.2 Results obtained

The duration of data collection was based by the fact that for substantial change of reactive power demand, there is no likelihood of substantial increase/ decrease of the load connected to the line as it was shown from national load profile that capturing of data at interval of four hours period will suffice as change of the load is gradual rather than instantaneous.

The data obtained is presented in both table and graphical forms. Time is categorized as day (08:00 – 18:00 hours) and night (18:00 – 08:00 hours) and the minimum and maximum IPF the energy meter recorded. The aim was to note what time of the day the feeder or transmission line has highest or lowest power factor. Based on the frequency of occurrence, the line was deduced as having low or high power factor. Considering the first column of the table 1 (transmission 1), 0.93 was the lowest IPF recorded by the meter during the day and 0.97 was the highest IPF recorded on Monday night.

The aggregate power factors captured were as depicted in tables (1), (2) and (3) hereunder.

3. Data analysis

The IPF captured reveals that the amount of reactive power delivered by the transmission and distribution lines primarily depend on the nature of the loads. This can be deduced by considering each of the feeder lines as follow.

i) Industrial Loads

Lines supplying industrial loads were noted have almost unity power factor at all the sampled substations. This is presumed to be due to the availability of VAr compensators installed at large power consumers hence relieving the lines delivering the reactive power from the source.

ii) Domestic loads

Lines supplying domestic loads have low power factor as there is no VAr compensation at domestic and small power end users. This implies that the reactive power required by these loads, which are mostly non-linear, have to be delivered by the transmission and distribution lines. It is worth noting that low IPF occurs mainly during the day time as numerous non –linear loads (such as computers, printers, scanner/ photocopiers) are used during the day hence raising the demand of reactive power. The feeder lines at substation C with power factor below 0.7 are distributing the active power at efficiency below 50%. This implies that more than half of technical losses on these lines are caused by reactive current.

iii) Mixed load lines

The data collected clearly shows that lines supplying both domestic and small scale industrial loads (mixed) have relatively low power factor, but higher than lines dominated by domestic loads. It is worth mentioning that low power factor occurs during the night and weekend. This can be attributed to dominance of domestic loads as some of the small scale industries are closed at night and such industries usually have miniature power factor correction capacitors for compensation of reactive power during the day on weekdays.

3. **Conclusion and recommendation**

The analysis of the data obtained in this work leads to the following conclusions;

i. It was observed that some of transmission and feeder lines are supplying the active power at low efficiency (low power factor) and especially lines supplying domestic loads. The most affected lines were those supplying domestic and mixed loads due to numerous non-linear and inductive loads whose reactive power is delivered from the source.

ii. To minimize the losses and negative effects of reactive power in the power system, it is imperative to take a mitigation measure to compensate the reactive power at the point of demand. This can be realized by installation of Fixed VAr compensator (shunt power factor correction capacitor) at lines supplying mainly domestic loads.

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Table 1. Instantaneous power factor captured at substation A

Day of the week	**Monday**: min and max (time captured)	**Tuesday**: min and max (time captured)	**Wednesday**: min and max (time captured)	**Thursday**: min and max (time captured)	**Friday**: min and max (time captured)	**Saturday**: min and max (time captured)	**Sunday**: min and max (time captured)
Transmission1 (Industrial load)	0.93 (Day) 0.97 (Night)	0.93 (Day) 0.97 (Day)	0.94 (Day) 0.96 (Day)	0.95 (Night) 0.97 (Day)	0.96 (Day) 0.97 (Day)	0.95 (Day) 0.96 (Day)	0.96 (Day) 0.97 (Day)
Line 1 (Mixed load)	0.93 (Night) 0.98 (Day)	0.96 (Day) 0.97 (Day)	0.93 (Day) 0.98 (Night)	0.94 (Night) 0.97 (Day)	0.95 (Night) 0.97 (Day)	0.95 (Day) 0.96 (Day)	0.95 (Night) 0.97 (Day)

From the table 1, the lines power distribution efficiency is high due to availability of numerous industries with Var compensators. This also implies that the technical losses for these lines are less as they mostly carry active power.

Table 2. Instantaneous power factor captured at substation B

Feeder / Day	**Monday**: min and max (time captured)	**Tuesday**: min and max (time captured)	**Wednesday**: min and max (time captured)	**Thursday**: min and max (time captured)	**Friday**: min and max (time captured)	**Saturday**: min and max (time captured)	**Sunday**: min and max (time captured)
Transmission1 (Mixed loads)	0.87 (Day) 0.94 (Night)	0.87 (Day) 0.93 (Day)	0.84 (Night) 0.92 (Night)	0.91 (Day) 0.93 (Night)	0.91 (Night) 0.93 (Day)	0.89 (Day) 0.93 (Day)	0.91 (Day) 0.94 (Night)
Line 1 (Mixed loads)	0.91 (Night) 0.94 (Night)	0.87 (Day) 0.95 (Day)	0.91 (Night) 0.94 (Night)	0.90 (Night) 0.95 (Day)	0.92 (Night) 0.94 (Day)	0.91 (Night) 0.94 (Night)	0.92 (Day) 0.96 (Day)
Line2 (Domestic)	0.92 (Night) 0.94 (Day)	0.88 (Day) 0.93 (Night)	0.89 (Night) 0.92 (Night)	0.91 (Night) 0.93 (Night)	0.91 (Day) 0.93 (Night)	0.91 (Day) 0.95 (Day)	0.92 (Day) 0.94 (Day)

From the table 2, it is noted that transmission 1 with mixed loads and line 2 carrying mainly domestic loads have the power factor relatively below 0.9. Domestic loads reactive current are usually not compensated and hence the line has to carry that current from the source. Line 1 with mixed loads was found to have relatively low power factor during the day as compared at night. It is presumed that during the night, the compact fluorescence bulbs which are inherently associated with leading power factor improve the line power factor.

Table 3. Instantaneous power factor captured at substation C

Feeder / Day	**Monday**: min and max (time captured)	**Tuesday**: min and max (time captured)	**Wednesday**: min and max (time captured)	**Thursday**: min and max (time captured)	**Friday**: min and max (time captured)	**Saturday**: min and max (time captured)	**Sunday**: min and max (time captured)
Transmission1 (Domestic)	0.65 (Day) 0.66 (Night)	0.65 (Day) 0.68 (Night)	0.65 (Night) 0.66 (Day)	0.65 (Day) 0.66 (Night)	0.64 (Night) 0.65 (Day)	0.65 (Day) 0.65 (Night)	0.64 (Day) 0.65 (Night)
Line 1 (industrial)	0.98 (Night) 0.99 (Day)	0.98 (Night) 0.99 (Day)	0.98 (Both) 0.98 (Both)	0.98 (Both) 0.98 (Both)	0.98 (Both) 0.98 (Both)	0.98 (Day) 0.99 (Night)	0.98 (Day) 0.99 (Night)
Line 2 (Mixed)	0.78 (Night) 0.80 (Day)	0.76 (Night) 0.82 (Day)	0.80 (Night) 0.82 (Day)	0.78 (Night) 0.81 (Day)	0.76 (Night) 0.83 (Day)	0.78 (Night) 0.80 (Day)	0.76 (Day) 0.80 (Night)

From Table 3, transmission 1 which is dominated by domestic loads such as TV sets, fridge, air conditioners and computer was found to transmit the active power at low power factor. The technical losses on this line, 50% is due to reactive current transmitted on the conductors and transformers. These lines dominated by domestic non –linear loads usually trip due to overloaded which causes the power outage. As mentioned earlier, lines supplying industrial loads are having a good power factor as reactive power is compensated at the vicinity of demand. This is because the large power consumers are compelled to compensate the reactive power otherwise are penalized (power factor surcharge penalty).

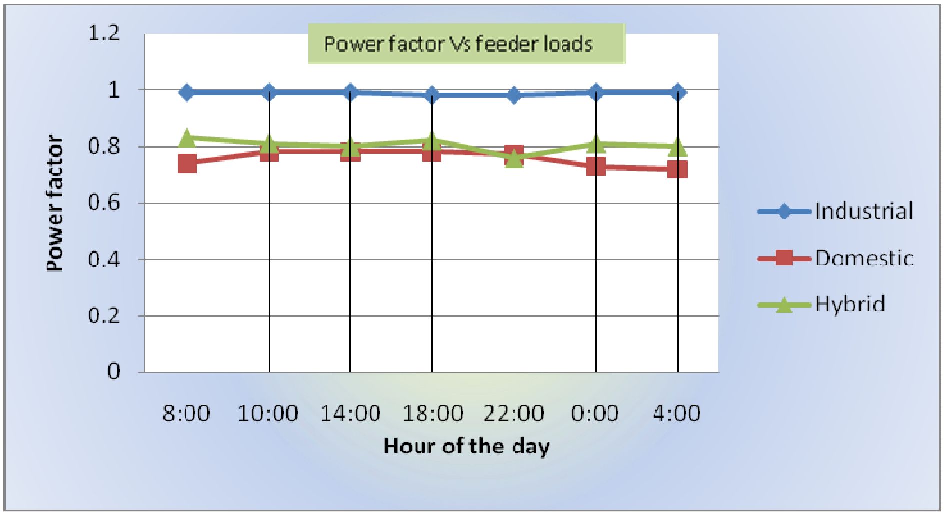

Figure 1. Varitions of power factor for a period of one day

The relationship between the power factor and nature of the load from the data collected is shown as a graph in Figure (1).
From figure (1), it is seen that the power factor and hence the efficiency of the line is determined by the dominant loads. Industrial loads maintain feeder power factor well above the statutory limit due to the installation of VAr compensators at the point of demand. Contrary, domestic loads cause the line to carry more reactive power hence lower the line power factor. Also, it is clear from the graph that when the feeder line is supplying mixed loads (and the domestic loads dominate the line which is mostly during the night and weekend), the line power factor is same as the line with domestic loads (*two graphs intersect*).