Unity Power Factor – A Myth

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In the recent past there has been a renewed interest in power factor improvement, driven mainly by the incentives (or penalties) for improving power factor. But over enthusiasm to improve power factor has resulted in both the regulatory authorities as well as the consumers targeting to achieve unity power factor. Though under ideal conditions this might be achievable and desirable, under practical circumstances this is neither achieve operation at unity power factor might go against the basic concept of power factor improvement.

1. **The primary purpose of reactive power compensation is not to maintain unity power factor, but to reduce the line currents and hence the line losses**:

   The above statement, though apparently looks contradictory, is absolutely correct. But in course of time we seem to have lost sight of our primary goal, that of reducing the line currents and hence line losses. It has been well established that operation at unity power factor is not always desirable, as contrary to popular belief, operation at unity power factor does not always lead to reduction in line currents, but rather at times results in increased line currents.

   This is due to the fact that power factor as normally understood, measured and compensated is the power factor (cosine of phase angle between voltage and current) at fundamental frequency. In no practical power system of large size it is possible to supply a pure sinusoidal voltage of a single frequency. Due to harmonics present in the system, the voltage always has higher frequency components. Due to the presence of these higher frequency components, though the compensation can be matched (i.e. capacitive current from the reactive power compensation system is made equal to the inductive current from the induction generator) at fundamental frequency, the high frequency capacitive and inductive currents do not match. This is due to the fact that the induction generator (or any inductive load) draws lower and lower currents at higher and higher frequencies, whereas the capacitor gives higher and higher currents as frequency increases. $\{I_L = (V/2 * (pi) * f * L)$ and $I_C = 2 * (pi) * f * C \}$

   This results in increased capacitive currents, more than that required by the parallel connected inductive load, resulting in this uncompensated capacitive current flowing all over the grid. This results in increase in line currents and line losses, at times more than what it would have been without compensation.

   It is well established that operation under conditions is not desirable, as this not only increases the line currents and losses but also results in harmonic distortion and other power quality problems. It can be shown that depending of the voltage harmonics there exists an optimum power factor (not necessarily unity) at which the line currents are the minimum and the customers and regulators should demand operation at this power factor!

2. **The primary purpose of reactive power compensation is just not to reduce lines losses, but promote sustainable development through conservation of scarce resources**:

If one could accept the first statement, the second one is only an extension. The purpose of all this compensation is to conserve the natural resources by reducing the line losses by power factor improvement. But one should not get carried away by this and overdo things. This is especially true for windfarms (or any load that is seasonal and highly varying) where the size of compensation required is very large to meet the requirements during a high wind season. But unfortunately only about 10 % to 30% of this will be utilized during a low wind season, which spans about 5 – 8 months in a year. Also the typical utilization factor of reactive power compensation systems in a windfarm type application is only about 14% - 22%. Probably it makes sense to put up a slightly smaller compensation, at the cost of not being to able to maintain unity power factor for certain period during high wind season, but improving the overall annual utilization factor. After all by installing a smaller system, one conserves the natural resources that would have gone into manufacturing and installing a large system!

3. The practical problems:

Apart from the above two considerations there are a few practical aspects that one needs to consider before demanding a unity power factor under all operating conditions. Some of these are as follows:

3.1: Operation at unity power factor under all operating conditions (“always”) leads to connection of large values of capacitors, which are not only expensive but calls for special protection and control features. These are required to protect the WEG from a possible over-compensation / self-excitation. Unlike most industrial loads, WEG’s are actually sources with a strong possibility of self-excitation thus endangering the entire turbine itself under certain operating conditions.

3.2: Considering the dynamic variations in power factor in a WEG, it calls for special controllers to maintain the power factor unity under all operating conditions. Even with the fastest of the available controllers there is always a definite time lag, during which period some part of the current would go uncompensated.

3.3: Apart from special controllers, the compensation system needs special / fast switches for connection / disconnection of capacitors. Use of normal mechanical switches might cause damage to the induction generator. Also considering the normal time delay required with mechanically switches systems, one has a tendency to add more capacitors to increase the availability, thus increasing the risk of over voltage on the system.

3.4: Even with the fastest of the controllers and switches, it still might not be possible to maintain unity power factor, as the two references for metering and compensation are different. To measure and compensate for power factor one a voltage and a current signal. These are obtained from PT’s and CT’s, which normally are of 0.5 % accuracy class.

As the reference for metering (EB) is taken from a set of instrument transformers that are different from those used for controlling the reactive power compensation system. Due to the ratio and phase angle errors and instrument accuracy the power factor as measured by two sets of instruments can be different. Considering the nominal errors associated with the system it can be established that the differences between two meters can be as high as 3%. What this implies that even if theoretically unity power factor is maintained by a set of instrument and controllers, the other instrument can still read an import (or export) of 3%, a power factor of 0.999.

4. Power factor versus losses:

It can be seen from table 1 that the line currents and losses do not increase proportionally with the % var import. This implies that below a certain % Q import (or conversely above a certain power factor) it is not desirable to improve the power factor any further. Similarly there exists a relation between power factor and blocked capacity and one could establish that at low (< 10%) Q import the blocked capacity is negligible and does not warrant any compensation.

Table 1. Increase in line loss versus power factor

%Q (=100*Q/P)	Power factor	% increase in line loss
0	1	0
1	0.99995	0.01
2	0.99980	0.04
5	0.99875	0.25
10	0.99503	1.00
20	0.98058	4.00
30	0.95783	9.00
50	0.89443	25.00
60	0.85745	36.00

Conclusion:

Based on the above one can clearly see that operation at unity power factor is neither technically desirable nor commercially viable. There exists an optimum power factor at which the total losses are the minimum. The sizing & configuration of such compensation system should be done on a techno-economic analysis and the penalty for reactive power should reflect the true cost of reactive power. Else one could end up adding a large amount of capacitors (that too at the wrong location) that would go against the principle of reactive power compensation and sustainable development and endanger the induction generators, but would operate at unity power factor under all operating conditions!