REACTIVE POWER SUPPLY FROM PV INVERTERS IN DISTRIBUTION NETWORKS

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ABSTRACT

Due to fuel depletion and environmental crisis, many countries are switching into the renewable energy system. With the expanding solar net metering scheme in Sri Lanka the solar PV systems are evolving in the low voltage distribution network. Domestic and commercial consumers are contributing to the national grid by feeding pure active power. This paper describes the opportunity to feed reactive power to the gird instead of pure active power injection by changing the operational power factor. This study explains the theoretical background and analyzes the potentials and limitations in empowering the power quality with voltage regulation improvement, compensating peak reactive loads, reduction in line losses and improvement in line capacity. And also, analyzing the opportunity in replacing capacitor banks for the reactive power compensation for peak loads with solar inverters. Then, compares the economic viability of this concept with various studies to promote this scheme.

Keywords: power factor, total harmonic distortion, voltage regulations

1. INTRODUCTION

Displacing fossil fuels due to fuel depletion and climate change-related issues gain great attention towards renewable energy systems(Santos-Martin, D., Lemon, S., Watson, J. D., Wood, A. R., Miller, A. J. V., & Watson, N. R., 2016). Renewable system acts as distributed generators. As a result, rooftop solar photovoltaic (PV) systems are rapidly increasing in Sri Lanka with the promotional program conducted by the government of Sri Lanka called 'Soorya Bala Sangramaya' (Soorya Bala Sangramaya, 2019).

In a grid-connected solar PV system, it can feed reactive power to the grid instead of pure active power injection. This concept supports with utility's objective to reduce line losses and improve voltage profile.

Presently, PV inverters are not utilized for reactive power supply in Sri Lanka due to the available tariff methodology that doesn't address a rate for reactive power(Navoda & Rodrigo, 2017). This paper analyzes technical opportunities, challenges, possible benefits and costs.

2. METHODOLOGY

2.1 Background

Power factor is the ratio between working power (*P*) to apparent power (*S*). In pure resistive loads (such as an electric lamp or electric heater) the Current is

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in phase with the voltage and there is 'unity' power factor. Inductive and Capacitive loads (such as an inductive or motor capacitor banks respectively) will cause the current to 'lag' or 'lead' the voltage, resulting in a 'non-unity' power factor. The lagging and leading nature clearly shown in figure 01.

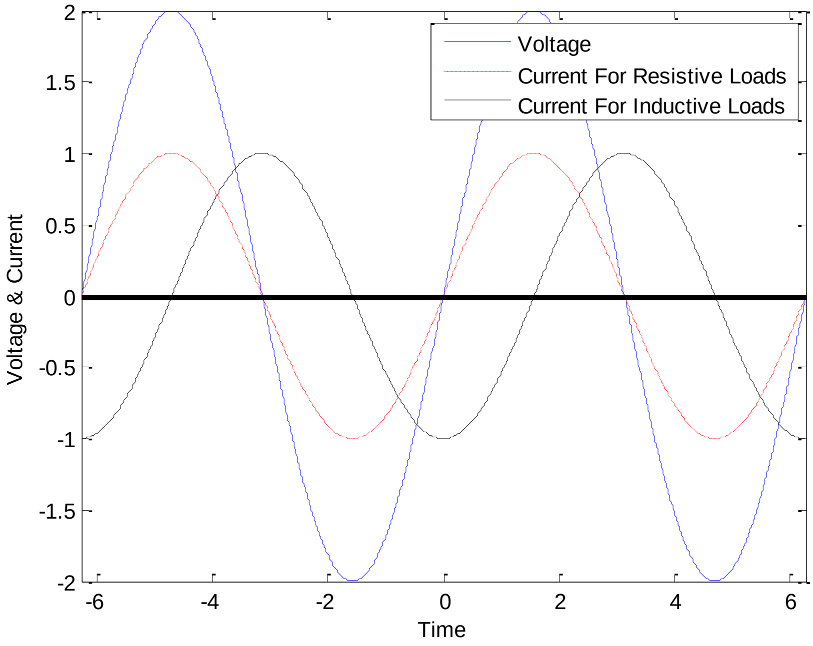

Figure 01: AC Power Systems with Unity and Lagging Power Factors

The relationship between active and reactive power clearly shown below in figure 02.

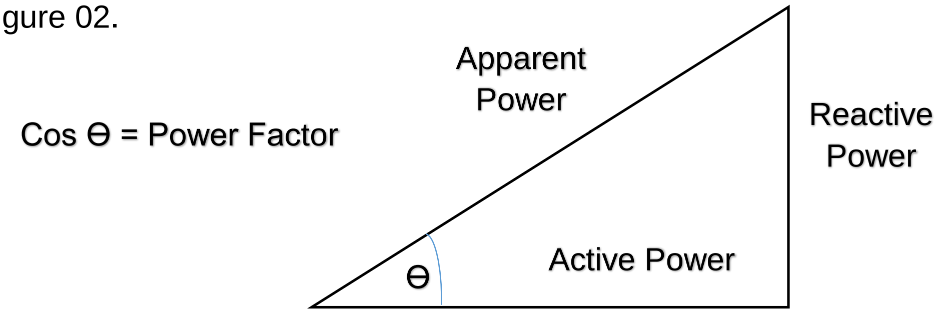

Figure 02: Phasor Diagram of AC Power

As can be seen from the phasor diagram (figure 02), increasing the reactive power increases the apparent power but, has no effect on the active power. This means the system must supply more apparent power even though there is no additional work being done by the system (as there is no increase in active power). Therefore, the power factor should be corrected locally. The most common practice is using capacitor banks. It is also being practiced in Sri Lanka due to the charge for maximum demand (in apparent power) for commercial users. And also, the utility installs it in transformer stations and substations.

Solar inverters are technically capable to operate at non-unity power factors as well. It provides us an alternative for capacitor banks that should be installed separately in the grid to maintain power quality by the utility.

2.2 Reactive Power Capabilities in Inverter

In principle all inverter-coupled generators, also PV generators are capable of providing the reactive power. It is possible to control active and reactive current independently from each other with constant maximum current, that is determined by the solar irradiance (Braun, 2008). We consider apparent power S_{max} instead of maximum current with active and reactive component P_{max} and Q_{max}.

$$Q_{max}^2(t) = S_{max}^2 - P_{max}^2(t) \qquad (01)$$

The control of reactive power (*Q*) can be done by varying the power factor of an inverter. But, it has limitations due to stability issues by total harmonic distortion (THD). The relationship between THD and power factor is illustrated in figure 03. This graph is simulated with different power factor levels with various capacitors' values using MATLAB/ SIMULINK software (Ahmad & Khan, 2012).

While analyzing the graph the power obtained is more below 0.85 power factor. The Inverter performs relatively better in the power factor range of 0.8 to 0.9. But, can't afford to reduce beyond 0.77 as the increasing nature of THD.

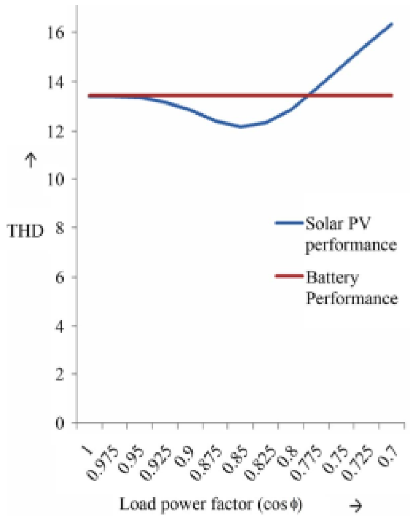

Figure 03: THD vs. power factor (Ahmad & Khan, 2012)

2.3 Motivations for Reactive Power from Solar Inverters

a. An alternative for Capacitor Banks

When it comes to reactive power compensations in-network, capacitors are sufficient in most of the situations. Braun (2007) compared in his work about the cost of the capacitors and PV inverters in terms of reactive power compensation capacitors are preferred. But, PV inverters are able to tackle the peaks of reactive demand as a short term basis. Also, PV inverters can follow smoothly the demand.

b. Improving Network Operation

Voltage regulation is a key factor power of quality. It can't be allowed to exceed it beyond a certain level. The inductive coupling in the transmission network and resistive coupling in distribution network leads to different scenarios of voltage control. The enhancement of voltage regulation by using a power factor control method proposed proposed by AS/NZ 4777.2 standards is given in figure 04. This is compatible with under-voltage and over-voltage issues(Santos-Martin et al., 2016).

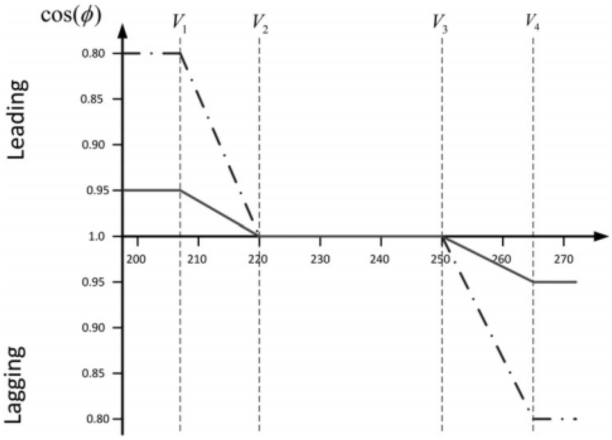

Figure 04: power factor control of PV inverters. Adopted from "draft Australian/ New Zealand standards (AS/NZS4777.2)"

For under-voltage issues, the inverter operates at leading power factor and in case of overvoltage it operates at lagging power factor. Sri Lankan power system mostly subjected to under-voltage issues(Navoda & Rodrigo, 2017). Under-voltage, issue analyzes in the study of Rodrigo and Navoda (2017) using a load flow model it concluded that low voltage issue can be upgraded along the distribution line.

Another improvement is reducing line losses,

$$I = \frac{\sqrt{P^2 + Q^2}}{V}, \qquad (02)$$

where line current(I), phase voltage(V). By injecting reactive power at the load side increases the voltage and reduces the line current. The line losses reduce with the reduction in line current.

The maximum transfer capability of a system is given as:

$$P_{max} = \frac{V^2(-k + \sqrt{1 + k^2})}{2X}, \qquad (03)$$

where $k = \frac{P}{Q}$ and reactance of the system (X). Similarly, maximum power transfer capability increases with reduced current flow. Eventually, the reliability of the transmission system improves as well (Kutkut, 2012).

Also, several studies show that there are possible economic benefits for choosing reactive power supply of PV inverters since it is already available in the grid that doesn't want an additional investment regardless of compensation for consumers (Braun, 2007; Kutkut, 2012).

2.4 Cost Factors for Reactive Power from Solar Inverters

Initially, the focus has been on active power for rooftop solar PVs. Extending our scope to the reactive power supply lead us to additional losses. It described by the following equation developed by Braun (2007). Inverter losses can be assumed independent from the power factor and P_{AC} can be substituted by S with only small errors.

$$P_{loss}(s) = c_{self} + c_{Vloss} \cdot S + c_{Rloss} \cdot (S)^2, \qquad (04)$$

with self or no load losses (c_{self}), terminal voltage dependent losses (c_{Vloss}), current dependent losses (c_{Rloss}) and small errors (s). The losses are categorized into two different scenarios that are day time and night time operations.

During the daytime, the inverter feeds active power that is generated by the PV modules into the grid. The additional losses accompanying the reactive power supply reduce this active power injection. Hence, the costs of the additional losses are the opportunity costs due to a reduced active power supply.

During the night, the PV modules do not provide any active power. The inverter losses due to the reactive power supply are then compensated by the external grid resulting in costs due to the tariff of active power purchase.

Oversizing of the inverter is often needed in order to obtain full availability of reactive power(Braun, 2007). It leads to additional investment cost that is undesired for consumers. Hence, to obtain their attention there must be promotions to be done.

Inverter lifetime assessment for injecting reactive power to gird needed attentions on capacitor degradation and additional thermal stress on inverters. During the study on inverter lifetime assessment, comparing benefits and cost of a PV inverter for reactive power injection it is economically viable(Gandhi et al., 2019).

3. CONCLUSION

This paper study the feasibility of reactive power compensation using solar inverters in economic and technical terms. As a customer premises equipment, solar inverters can be utilized for empowering the grid. The implementation is also possible as most of the market available inverters are capable enough to supply reactive power as well. In addition, we can operate inverter within 0.775 power factor range as further reduction increases the THD. It is preferable to operate in 0.85 power factor where results in superior.

Moreover, relevant compensation should provide to consumers by considering the benefits and costs. Existing tariff methodology must be revised in terms of reactive power usage. Because, tariff only contains maximum demand charge to account reactive power usage which is inadequate. And also, we must properly address economic benefits for consumers to use their inverters by considering aforementioned cost and benefits. This scheme would increase the overall economic efficiency of solar inverters.

4. ACKNOWLEDGEMENT

This study was done under the supervision of Resource Management Associates (Pvt.) Ltd. I express my thanks for providing me training facility and their intellectual supports and encouragement. I also extend my gratitude to our department staffs for motivating to write this concept paper.

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