Shunt Compensation in a Solar Micro-Grid System

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Abstract - *The implementation of the solar Micro-Grid system has become very obsolete because of the poor power management. It is given the least importance for the vast production of power due to the power instability that the consumer or the private agency face after its successful implementation. Therefore a necessity was felt to improve the power stability that can be achieved by controlling the level of reactive power that is being produced after the DC is converted to 3phase AC. Generally, it becomes difficult to maintain a good power factor in Solar PV to grid connected Power System, so the focus shall remain mainly on improving the power factor with the help of Shunt Compensation.*

Key Words: **Shunt Compensation**, **Solar Micro-Grid**, **Power factor correction**, **Reactive Power Compensation**

1. INTRODUCTION

As the human population on the earth is rapidly increasing day by day, resulting in increase in the demand for power. This situation shall firmly increase in upcoming days if not taken care properly. Also, there is an immense problem of frequent power failure, that affects a lot of productive work. And most of the time, it has been observed that these power failures are the consequences of either frequency mismatch or system instability due to some problems in the power system such as a sudden increase of demand for power or the natural calamities affecting the power system. So, the only choice we are left with is using of the renewable energy sources and converting them into electrical energy, so that we can meet the power demands of the population. For this, solar energy is one of the finest choice that one can come up with, in this kind of situation.

But, using solar energy and synchronizing it with the grid to meet the daily power requirements becomes a matter of concern as the most important factor that acts upon delivering power to the users, is the quality of the power delivered. So, providing quality power to such a large population is a big challenge for the grids. Quality power is nothing but the power having a smooth voltage curve and frequency close to the rated value, that keeps the power system stabilized. But reactive power is something that affects the voltage curve and makes it fluctuating, as a consequence the power factor is affected.

In order to improve the power factor, we have considered the method of shunt compensation, where a capacitor bank is connected in the middle of the transmission line, that draws the current, making it to lead the source voltage and hence the power factor is improved, making it suitable for the use by the consumers.

2. PROJECT DESCRIPTION AND GOALS

PV to grid connected system block diagram in Figure 1 describes the components that are mentioned in reactive power compensation and Solar PV to grid power flow.

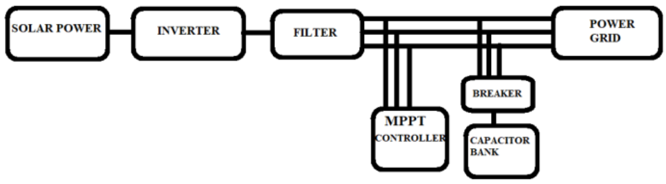


Fig-1:- Block Diagram of the Solar PV to grid connected system

We shall not focus on the complete details of the components used rather our focus shall be more on the output generated. Below are the few points described to gain some insights about the few components used.

2.1. PV System

Fig-2: Solar PV-Cell

The solar cell works on the principle of photoelectric effect that intakes the solar radiations with certain irradiation value (we have considered the irradiance to be $200W/m^2$). The fig-2 depicts the solar arrays that consists of two plates that are sandwiched and are generally made up of Silicon material.

In early days, Selenium was used to frame the panel but with Silicon it was observed that the solar energy stimulates the electrons rapidly to leave the hole as compared to Selenium, as Silicon is a poor conductor of electricity. Moreover, when the solar energy consisting of photons fall on the surface of PV Cell, then the electrons gain some energy and come out from atom generating a flow of electricity.

2.2. Buck-Boost Inverter and Control

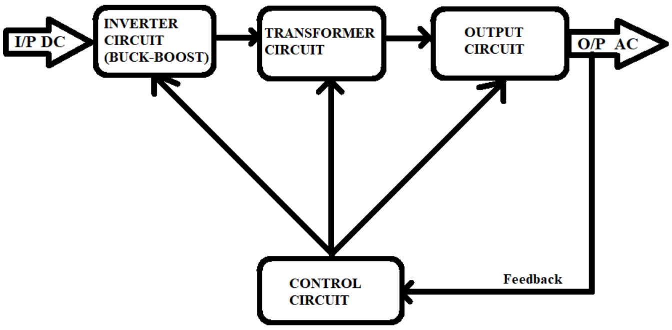


Fig-3: Inverter control scheme

The output voltage that was obtained from the Solar PV-Array was allowed to enter the DC-AC Converter, that is connected to the inverter controller MPPT (Maximum Power Point Tracking), to maximize the power obtained from the Solar PV system under all conditions. The block diagram of the inverter control is shown in fig-3.

The inverter that we used for the simulation was a buck-boost inverter which helps in lowering the harmonics by the help of a Pulse Width Modulation drive producing output AC voltage in a magnitude greater as compared to the input DC voltage.

2.3. Filters

The filters used in the system after the inverter, are basically needed to reduce or minimize the Electromagnetic interference that the output of the inverter is subjected to. So in order to achieve noise free output, filters with modern power conversion and switched mode techniques that provides us the highest possible efficiency within a reasonable cost and size are used.

In this case, the kind of filter circuit that's preferred is an L-C filter of a forward or buck converter whose circuit diagram is shown in fig-4.

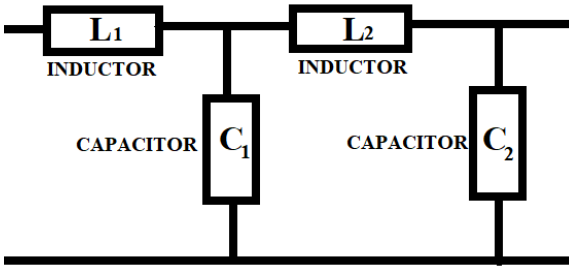


Fig-4: L-C forward filter

2.4. Shunt Capacitor Bank

Based on certain parameters such as active and reactive power, voltage, power factor, we need to take certain actions to counter the instability that might occur in the transmission line. In our case we considered the problem to be the low power factor. So in order to prevent the low power factor conditions, we add a shunt capacitor to the transmission line as shown in fig-5. When the transmission line experiences inductive load, the load current tends to lag voltage, as a result the power factor lags. In order to compensate it, shunt capacitor is used that results in drawing the current that's leading the source voltage and hence overall power factor is improved.

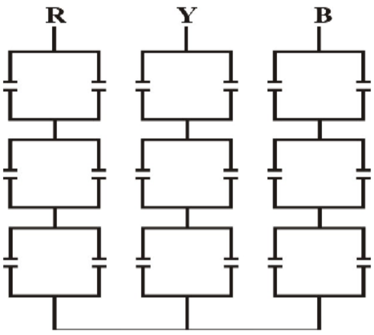


Fig-5: Capacitor Bank

3. POWER FACTOR IMPROVEMENT

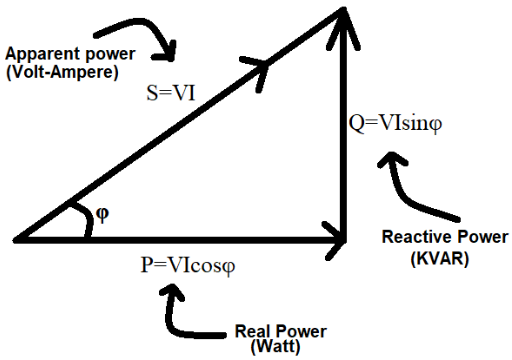


Fig-6: Power Triangle

From the power triangle shown in fig-6,

- **Power factor, φ = P/S (1)**

And hence,

- **Real Power, P= VIcosφ (2)**
- **Reactive Power, Q= VIsinφ (3)**
- **Apparent Power, S= VI (4)**

It can be clearly observed that, power factor (1) is the ratio between the active power and the apparent power. The real power is maximum when the "**cosφ**" is maximum and the "**cosφ**" is maximum when **φ** is minimum.
Therefore from the above equations we draw a transparent conclusion regarding the relation between the power factor and the other parameters. As the power factor changes there is a change observed in real and reactive powers whose amount decides the stability of the system. Hence power factor is an important factor that plays a vital role in maintaining the stability of the system.

3.1. Need for Power Factor Improvement

The power factor can be manipulated by adding certain elements in the transmission line but our main concern of improving the power factor includes the adding of shunt capacitor bank so that the current carrying capacity of the transmission line increases and as a result the power losses decreases to a certain extent. And this will lead to the increased reliability and efficiency of the solar micro-grid system.

4. SHUNT COMPENSATION

In order to provide flexibility to the power system the shunt compensation is one of the best options to implement so as to make the system more reliable and efficient. With the help of shunt compensation the following objectives can be fulfilled:

- It makes the line more compatible with the prevailing load demand of the users.
- This helps in increasing the power factor near about unity that makes it perfect to transmit maximum power through the load.
- More importantly, the transient stability with the shunt compensation is more making it comply with the conditions of ideal power transmission systems.
- Moreover, the voltage profile of the transmission line gets improved as the reactive power transfer is controlled to a minimum level, consequent to which the system becomes fast.

5. TECHNICAL SPECIFICATIONS AND DESIGN

Depending on the specified power factor, the quantity of reactive power that has to be reduced is calculated and hence the quantity of parallel capacitance needed to accomplish the reactive power is calculated and translated into the right number of capacitors that require to be turned on within the capacitor bank.

As per the project requirements we have set the specifications of the equipments in compliance with the IEEE standards and hence the quantity and ratings of the equipments were designed for a small scale testing of the reactive power compensation using Shunt compensation method in a Solar Micro-grid system.

The following are some of the specifications that should be taken care of, while designing the circuit in a grid or in a simulation.

Parameters	**Details**
Type of Solar PV Module	Mono or Poly Crystalline Silicon
Peak Power rating of the module	> = 250 Wp
Module Efficiency	> = 15.5%
Fill Factor	> = 0.75

Table- 1: Solar PV module specifications

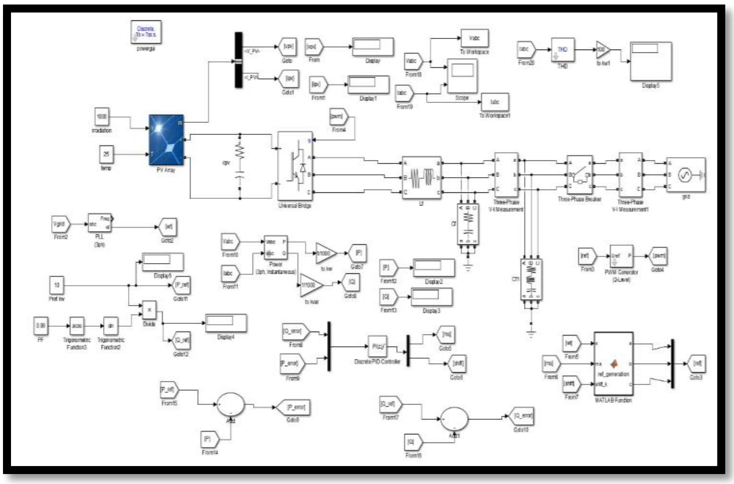
Table-2: Capacitor bank specifications

Parameters	**Specifications**
Fusing Type	Internally Fused
Power Range	300 – 1200 KVAR
Voltage Range	1 – 14.4KV
Frequency	50 or 60 Hz
Temperature Range	-50 to +55^{0}C

Table-3: Buck-boost inverter specifications

Parameters	Specifications
Switching Devices	IGBT/MOSFET
Nominal AC O/P voltage	415V(3-ph)
Output Frequency	50Hz
Grid Freq. Synchronization	+3Hz or more
Ambient Temperature	-20^{0} - 50^{0}C
Inverter Efficiency	> 93% (for 10KW or above)
Total Harmonic Distortion	< 3%
Power Factor	> 0.9

6. SIMULATION AND RESULTS



6.1. MATLAB SIMULINK Model

Fig-7: MATLAB Model

The MATLAB model that was prepared to realize the power factor improvement is shown in fig-7.
Few components included in the above model are shown below:

i. PWM Generator

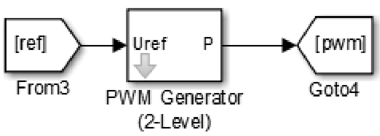


Fig-8: PWM Generator

The PWM generator have been introduced in the system as shown in fig-8, in order to compare the carrier frequency with the modulated frequency to generate the required pulse for the system.

ii. Phase Locked Loop (PLL)

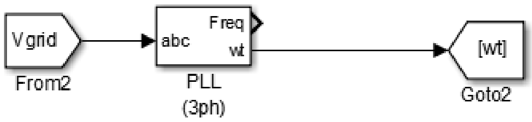


Fig-9:PLL

The PLL is used in the system, as shown in fig-9 so as to synchronize the phase sequence and frequency of the power grid with the inverter used.

iii. PID Controller

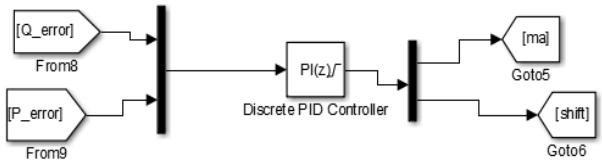


Fig-10: PID Controller

The PID controller uses the error signal and helps the system to give maximum power output with higher accuracy and speed. From fig-10, it can be seen the error signals of P & Q are taken as input to the system.

iv. Total Harmonic Distortion (THD)

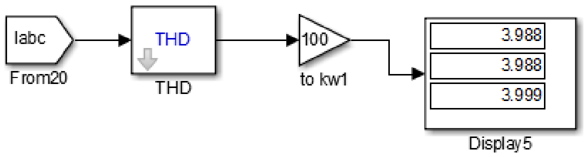


Fig-11: THD

The THD is the most important section of the grid as it is used to measure the distortions or the deviations that have taken place from the original values of few parameters such as power factor, peak currents and many other parameters. The lower the THD factor, the higher is the efficiency. From fig-11, the values of the distortion can be seen from the display.

v. Generation of reference signal

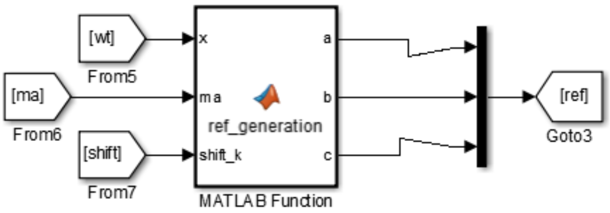


Fig-12: generation of reference signal

The outputs of the Phase Locked Loop and the PID controller are used as input variables to the MATLAB function block whose code is written on the command window, which processes the input and generates a reference signal as shown in fig-12. This reference signal is then used as input to the system.

6.2. Results and Waveforms (After Compensation)

i. Solar PV-Array outputs (DC)

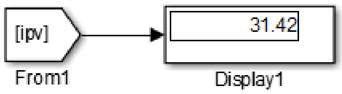


Fig-13: Outputs of Solar PV system

- Current output- **31.42 Amperes**

ii. THD output

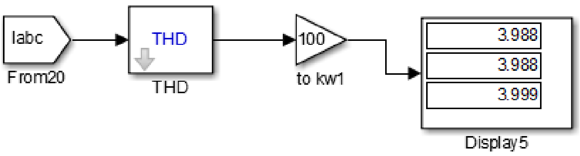


Fig-14: THD Output

- The total harmonic distortion (in %) – **4 (Approx.)**

iii. Power & Power Factor Output

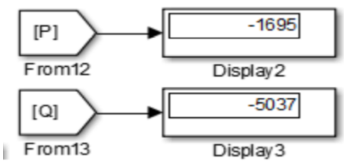


Fig-15: Power output

- Real Power, (P) = **1695 KW**
- Reactive Power (Q)= **5037 KVAR**
- Power Factor (φ) = **0.9 leading**

iv. Reactive Power

- **Before Compensation**

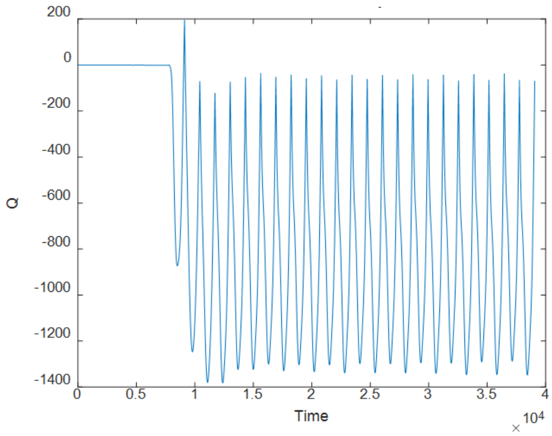


Fig-16: Reactive power before compensation

- **After Compensation**

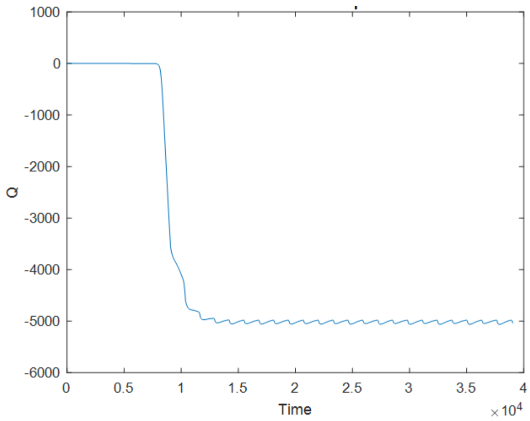


Fig-17: Reactive power after compensation

v. **Active Power (remains same)**

- **Before Compensation**

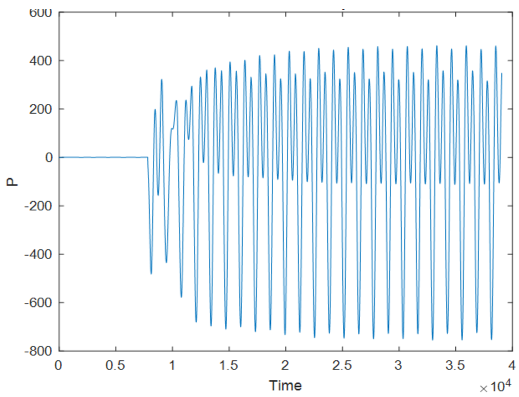


Fig-18: Active power before compensation

- **After Compensation (no change)**

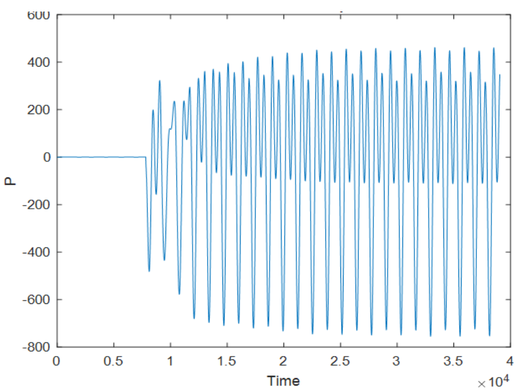


Fig-19: Active power after compensation

vi. **Load side Voltage (3-ph)**

- **Before Compensation**

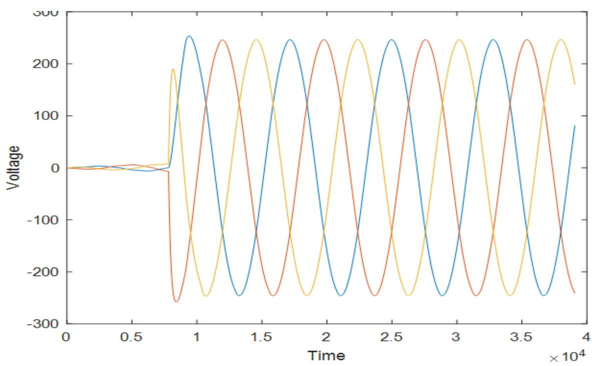


Fig-20: Load voltage before compensation

- **After Compensation (amplitude increased)**

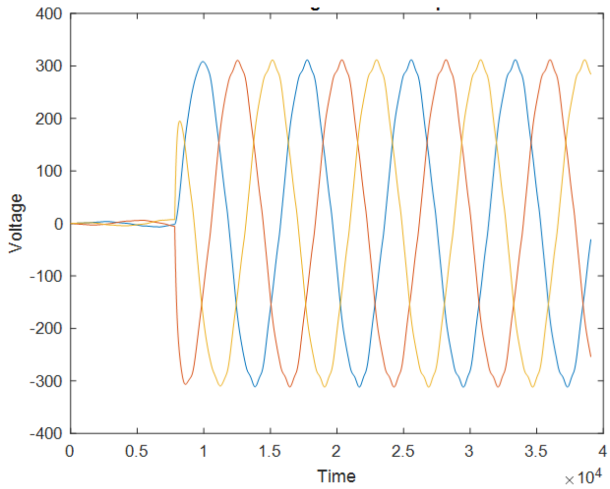


Fig-21: Load voltage after compensation

7. RESULT ANALYSIS

From the waveforms and output values seen from the figures, it can be concluded that:

- After the shunt compensation, the power factor although didn't improve to a larger extent but this arrangement surely helped to gain some points and the power factor went to 0.9 leading from 0.86 leading.
- The active power in the system remained same as that before compensation because the capacitor bank helped manipulate the reactive power and not the active power.
- The reactive power decreases and gives approximately a constant value near about 5037KVAR after some time interval.
- The 3-phase load voltage gets increased after compensation, which again was the main concern of the project to achieve and hence achieved.
- Most importantly, it was observed that the solar PV array at certain irradiance level is capable generating power that can directly be synchronized to the grid without facing much losses in the system.

- A rough cost analysis was done for this project which implies that the cost involved is mostly for the setup whereas the operational cost is comparatively low, making the project suitable to implement in a large scale and that too using renewable energy source.

8. CONCLUSION

Hence from the output waveforms, it can be concluded that there are certain distortions occurring during the compensation process but the ultimate concern of improving the power factor of the system worked well that went from 0.86 leading to 0.9 leading, which a milestone to achieve from this project. This project has already been implemented by the government in the grids since long ago, but it's uncommon in solar PV to grid-connected systems. Because in India we have most grids with power arriving from the generating stations and not from the Solar Generation. So there is a little scope of following the Distributed generation method in India. May it be due to the high cost of installation and maintenance of solar panels or due to the less availability of land. So wherever there is the scope of Distributed generation, the power compensation issue arises, which this project aims to resolve by improving the power factor with the help of shunt compensation. Further, we aimed at reducing the cost of the installation of the solar panel which was not resolved fully but to some extent can be followed. Since we were not accessible to the physical conditions of testing the project, hence all we obtained is the result of the simulation, that may vary with the real-time operations. Also, we are concerned about bringing improvements in near future, where a brief study is required in order to understand the working of the grids, which shall act as a developing step for the Power System of the country.

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BIOGRAPHIES

M. Ashish Kumar is an impassioned electrical graduate from PMEC, Berhampur, curious and willing to explore the improvements in Power Transmission and Distribution systems and working on increasing the power carrying capability of the line. Moreover, he has been a research intern at IIT BOMBAY for the session 2019-2020.

Prof. Pravat Mohanty is a highly experienced faculty serving as Assistant Professor in the dept. of Electrical Engineering at PMEC, Berhampur. He has specialization in Power System Engineering and is adept at skills with in-depth knowledge in Power systems and Power drives.