Enhancement of Power Quality of Single Stage Grid Connected PV System by Using Takagi-Sugeno-Kang Fuzzy Controllers

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Abstract: Grid connected solar power plants are widely established in many places worldwide. Photovoltaic (PV) based grid connected solar plants are attracting recently due to improved in controlling of power converters. Single stage grid connected systems can reduce number of converters connected in power plants which resultant in reduce cost of the system. However, DC to DC converters are generally used in PV systems to enhance the operation of maximum power point for best utilization. The inverters also can be using to extract maximum power from PV systems through new controlling techniques in power electronics devises. Therefore an extraDC to DC converter is not required to make PV at its maximum power point condition. However, this technology can be used for small scale solar power plants since all PV arrays in solar power plant cannot be received same irradiance. Takagi-Sugeno-Kang (TSK) fuzzy controlleris having significant priority than proportional plus integral controllers when rapid changes are having in input. Hence, TSK based single stage controller is developed in this paper for grid connected 1MW solar plant. Generally distribution system is connected with unbalanced loads, hence these unbalanced loads will create forcefully unbalanced currents in electrical grid. Unbalanced grid currents further create many problems to other loads. Therefore, the proposed controller is designed to help making grid currents balanced during unbalanced local loads. Further, the inverter can compensate reactive power demanded by local loads to minimize reactive power supplied by grid. Extensive results are presented and evaluated through hardware-in-loop on the platform of OPAL-RT to enhance the performance of proposed controller for 1MW grid connected solar plant.

Keywords: Photovoltaic, Hardware-in-Loop, Single stage, MPPT.

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1. INTRODUCTION

Many nations throughout the world are supporting the construction of solar power facilities in order to reduce green house gases [1-2]. Electricity provided by photovoltaic (PV) module-based power generation units is becoming increasingly prevalent. Various grid-connected small-scale PV systems have been developed worldwide. A DC to DC device is often installed between the inverter and PV unit to ensure stable voltage at dc-link while also achieving maximum power for optimal usage [3]. This extra device raises the total system price as well as the needed maintenance. Because new control methods are being developed in power converters, the inverter may now function to meet DC to DC circuit objectives such as maximum power point tracker (MPPT) and controlling voltage at the dc-link. Furthermore, there is no need for a battery to store electricity in a grid integrated models because the electricity generated by PV modules is immediately injected into the grid. As a result, the inverter should be adjusted to account for variations in both solar irradiation and local loads. Hence, a new control method for inverters is presented in this study to avoid using an extra DC to DC circuit.

In 1999, power Grid Company of India limited prepared a draft copy of the Indian electrical grid code under the guidance of the Central Electrical Regulatory Commission [4]. These grid codes specify a substation with 33kV/11kV transformers as the link between the grid and the distribution system. As a result, the whole distribution system operates at 11kV and then steps down (typically 400L-L rms) to the rated voltage as required by the loads. Locally placed PV plants will be integrated at the substation's 11kV transformer. Many local loads are connected to the same substation with various transformers at the same time. These local loads are often single phase or three phase. As a result, imbalanced currents will always occur at the substation. In addition, many loads require reactive power. This causes several issues in the main electricity grid. Aside from these issues, solar irradiance is always randomly varying, and load demand will fluctuate dramatically from time to time. In general, proportional plus integral (PI) controllers cannot provide optimal performance under these conditions in real time [5]. To address these issues, a new control method using Takagi-Sugeno-Kang (TSK) fuzzy controllers is built for a 1MW grid integrated PV system.

Section-2 shows the description of the grid integrated PV system along with ratings of the PV unit, whereas Section-3 shows the suggested control method of the inverter. The OPAL-RT platform is used to assess hardware in-loop (HIL) findings in Section-4. Section-5 follows the conclusion of this study.

2. SYSTEM DESCRIPTION

The inverter is the only power circuit between the grid & the PV unit in a single stage grid integrated PV unit. As a result, the inverter must manage the voltage at dc-link, function as an MPPT converter as well as to manage active and reactive power at load bus. Unfortunately, a single PV module cannot provide enough voltage at the dc-link [6-7] to inject current into the power lines of the grid via the inverter. As a result, 'N' modules are linked in series to form a PV array in order to raise the voltage. Similarly, 'M' PV arrays are joined in parallel to form a PV system capable of maintaining rated current. Table-I lists the needed ratings for establishing a 1MW PV system or solar plant. Individual MPPT converters are thus necessary to extract the maximum power from a set of arrays in relation to the matching amount of solar irradiation. Using additional converters, on the other hand, will not result in a single stage system. As a result, single stage systems may be used efficiently for small-scale solar plant capacity. A single stage grid integrated PV unit is not

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recommended for high power PV plants unless a large number of inverters are used for a specific group of PV units.

Table-I: 1.0MW solar power plant parameters

Single module (215.0W)		
S.No	Parameters	Values
1	Current when Short-circuited	8.01A.
2	Voltage at Open-circuit	36.9V.
3	Voltage at MPP	30.3V.
4	Current at MPP	7.10A.
Series-parallel arrangement for 1.0MW		
5	'N' in Array	600
6	'M' in PV System	8.0
Other ratings		
7	Voltage at PV dc-link	18.2 kV
8	Total power (average)	1.0 MW

Various local loads are linked to the point of common coupling (PCC) via transformer. To create a single stage grid integrated plant, the PV unit is linked to the PCC using simply an inverter. Figure 1 depicts the layout of a single stage grid-connected PV plant. Nonlinear, reactive and unbalanced loads are commonly employed at PCC, results serious difficulties in the electrical grid [8-11]. Active power filter and DSTATCOM are thus utilized at local substations to mitigate the impact of these loads on the distribution grid. This will result in a rise in the cost of power boards. As a result, the same inverter used in solar plants can correct reactive power requested by load while also making balanced currents in grid under imbalanced load at PCC while minimizing harmonics. Several researchers have lately proposed comparable types of study, and I have mentioned a number of them. The authors of [9] advocated using DSTATCOM in a grid-connected PV system to adjust for reactive power requested by the load. The authors of [10] propose a single stage grid integrated PV plant with enhanced MPPT and reactive power adjustment. The authors of [11] create an efficient energy management system for a single stage grid integrated PV unit with a storage device. The authors of [12-14] provided many forms of controllers for a single stage grid operated PV plant, although the system is only single phase. Furthermore, no author [9-14] addressed a TSK-based controller technique in a single stage grid-connected unit.

PV system power generation is affected by solar irradiation. Unfortunately, dramatic fluctuations in solar irradiance will occur. Due to their set gains, PI controllers will fail to function efficiently in this case. TSK-based controllers can function successfully for nonlinear systems with large variations in inputs [15-16]. As a result, TSK-based controllers must be created in order to provide a smooth performance.

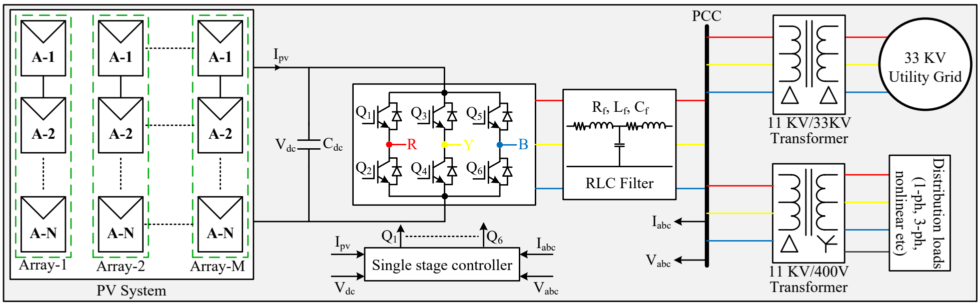

Fig. 1: Grid integrated single stage PV plant.

3. CONTROL OF INVERTER

To produce the most electricity, the PV module must be working at a certain voltage. Figure 2 depicts the power-voltage characteristics of a PV unit at various solar irradiances. According to Fig. 2, a PV array may provide the most power feasible by operating at the matching voltage level (V_{mpp}). In this study, the perturbed and observed (P&O) technique is utilized to detect the V_{mpp} signal. To run the PV array voltage at Vmpp, a physical converter such as a DC to DC device is necessary. However, to construct a single stage grid-connected system, the inverter is utilized to control dc-link voltage (Vdc) at V_{mpp} to operate as the MPPT converter of the PV array, allowing an extra converter to be removed.As a result, the inverter controller should be programmed to manage the dc-link voltage according to the V_{mpp} signal. However, V_{mpp} varies and is deemed a lower value at G=200 in order to provide appropriate AC voltage. However, by lowering the modulation index, an inverter may readily provide enough Ac voltage for irradiance greater than 200. As a result, at G=200, a limiter is utilized to restrict the lover value of V_{mpp}. Figure 3 depicts the block of the P&O technique.

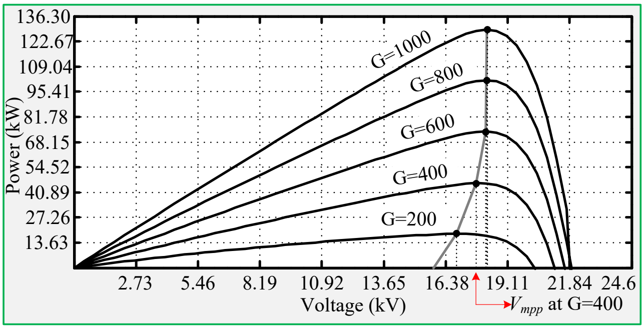

Fig. 2: Power-voltage characteristics at various irradiances(G).

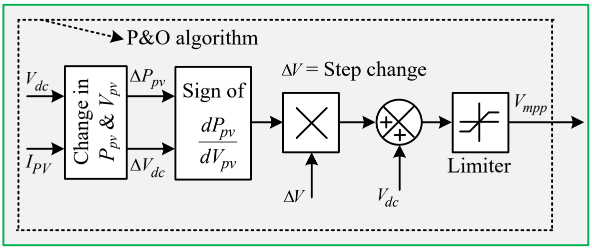

Fig. 3: MATLAB implementation of P&O technique.

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In general, power discrepancy between DC and AC can have an effect on dc-link voltage. If PV arrays provide more electricity, the dc-link voltage will be greater than its reference value (V_{mpp}). As a result, in order to inject currents into the grid via inverter, the controller must create a higher value of direct axis reference current (i.e. Id*). As a result, the reference signal (V_{mpp}) is linked to the negative side of the summing block, whereas Vdc is attached to the positive side. Furthermore, the reactive power required by loads connected to PCC will alter the RMS voltage at PCC. As a result, the reactive current component is determined by comparing the RMS voltages at its reference values. This can be beneficial for compensating for the consumption of reactive power. As a result, the drop across resistance must be considered to the voltage active component (i.e., V_d), and decupling components should be added to their corresponding axis reference value. Furthermore, the oscillating components of voltages in the direct and quadrature axes are added to their reference values. This can assist inverters in creating varied modulation indices to provide balanced grid currents when operated unbalanced load at PCC, as well as decrease harmonics caused by nonlinear loads.

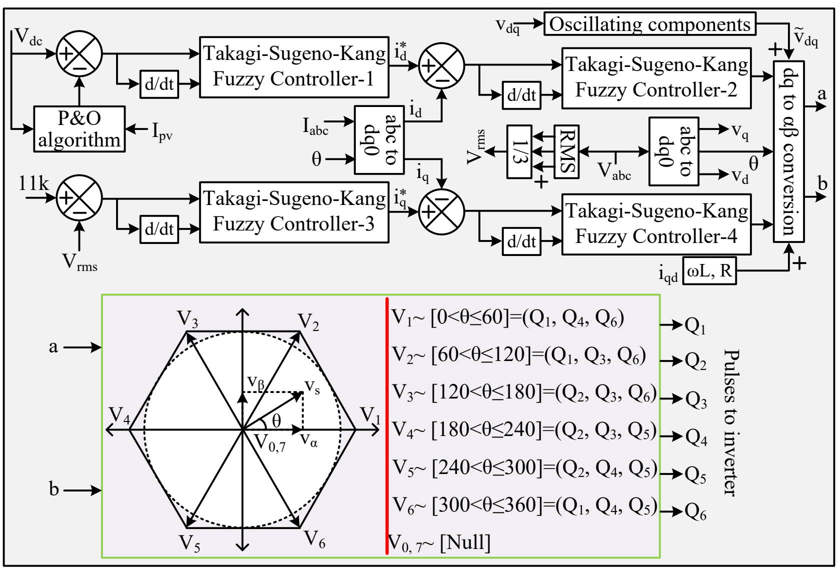

Fig. 4: Proposed control method for inverter with TSK Fuzzy.

The suggested inverter controller is shown in Fig. 4 and is based on TSK-based fuzzy controllers rather than PI controllers to get the greatest performance. The inverter controller presented in Fig. 4 must be constructed in order to regulate both dc-ink and voltage at the PCC. As illustrated in Figures 4 and 5, a TSK-based fuzzy logic controller accepts error and its derivative as input signals. It is powerful enough to solve complex nonlinear issues like as unanticipated variations in solar irradiation and load at PCC. These TSK fuzzy controllers are created using the mathematical formulae shown below and corresponding representation is depicted in Fig. 5:

$$\mu^L(u) = \begin{cases} 1 & if\ u \le c^L \\ 1 + \dfrac{c^L - u}{0.5w^L} & otherwise \end{cases} \quad (1)$$

$$\mu^{c}(u)=\begin{cases}1+\dfrac{u-c}{0.5w} & if\ u\le c\\ 1+\dfrac{c-u}{0.5w} & otherwise\end{cases} \tag{2}$$

$$\mu^{R}(u)=\begin{cases}1+\dfrac{u-c^{R}}{0.5w^{R}} & if\ u\le c^{L}\\ 1 & otherwise\end{cases} \tag{3}$$

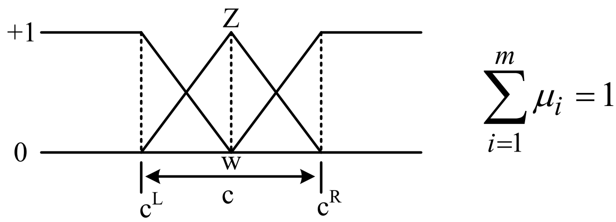

Fig. 5: Function block for membership.

The following membership functions are intended for the different TSK controllers shown in Fig. 4 in order to provide a valuable response under nonlinear fluctuations..

4. Results with HIL

The real time simulators (RTSs) are a digital simulator modules that can operate in real time by solving power system equations quickly enough to constantly provide output circumstances that truly mimic real-world network situations [1, 4]. RTS technology is widely regarded as an appropriate instrument for designing, developing, and testing power system control systems. Researchers employed two RTS modules produced by OPAL-RT technologies to implement the HIL configurations. Unit-1 hosts the whole plant model, whereas Unit-2 hosts the controls. Both devices are equipped with analog and digital cards that allow them to be connected to form a loop. Analog signals are sent from the plant to the control, whereas digital signals are sent from the control to the plant.Extensive findings are being extracted via another computer for examination. Figure 6 depicts the HIL model block by using two OPAL RT - 4510 devices. The suggested model, seen in Fig. 1, is separated into two parts: plant and controller. Figure 7 depicts a full block diagram of the proposed system's HIL process, complete with color labeling. The results are also reported in the case studies below..

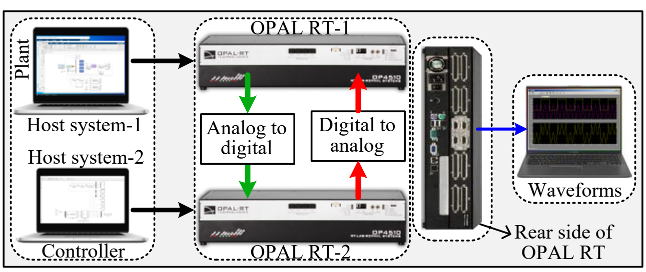

Fig. 6: HIL setup block.

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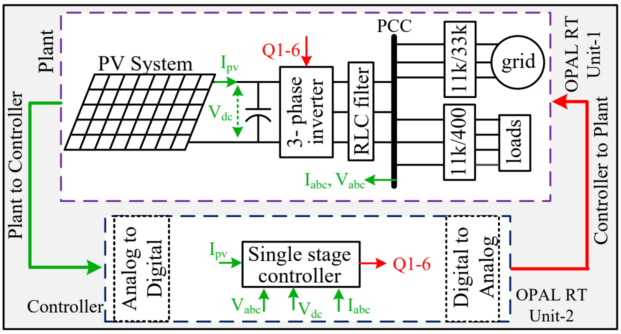

Fig. 7: The suggested model's HIL implementation

Case-1: *Inverter controller performance with imbalanced load supplied at PCC:*

Unbalanced load is typically linked to PCC because to 1-phase loads such as homes, straight lights, small size factories, and so forth. As a result, unbalanced voltage drops will occur at the filter, resulting in imbalanced voltages at the PCC. The currents supplied by the grid will become imbalanced as a result of the unbalanced voltage at the PCC. These imbalanced currents pose major issues for other grid-connected loads. As a result, maintaining balanced grid currents is critical to ensuring power quality. Balanced grid currents are obtained during the operation of unbalanced loads circumstances by injecting unbalanced three phase current via the inverter with the aid of the suggested controller.The suggested controller is evaluated for the imbalanced load current profile shown in Fig. 8. The controller creates varied modulation indices during this process to provide balanced grid currents, as illustrated in Fig. 9. The instantaneous and RMS voltages at PCC are depicted in Figs. 10 & 11, respectively. The minor decrease in Fig. 11 happened owing to a quickly connected imbalanced load at PCC. However, this drop is less than 1.0% and was swiftly corrected. This is achievable thanks of TSK fuzzy's quick responsiveness to abrupt changes.

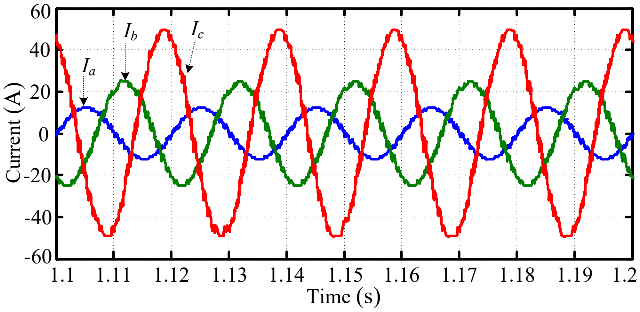

Fig. 8: PCC has an unbalanced load.

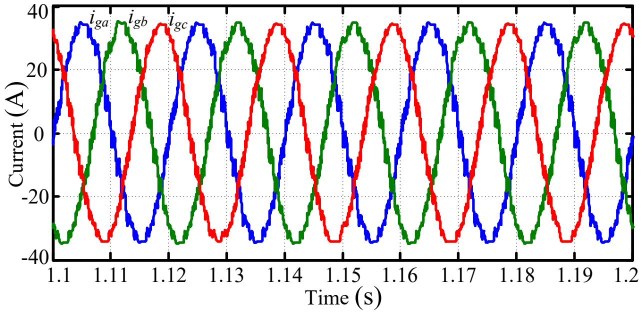

Fig. 9Grid currents that are instantaneously balanced

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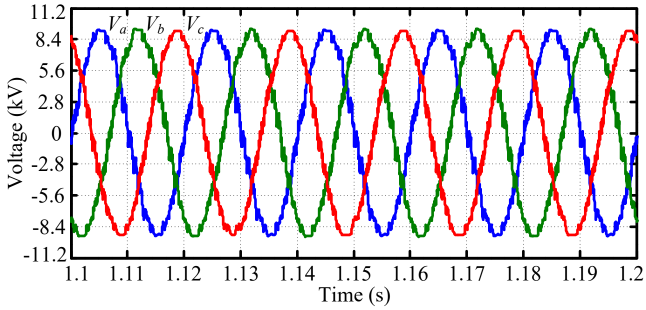

Fig. 10Grid/PCC instantaneous balanced voltages

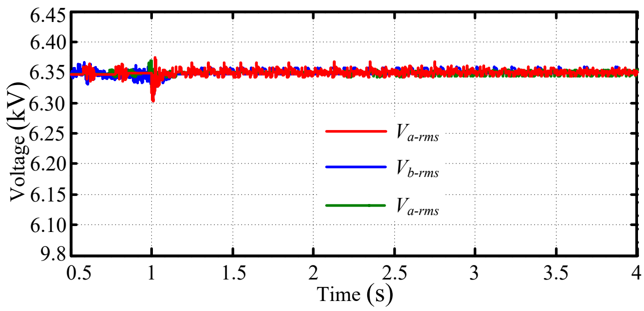

Fig. 11: RMS voltages.

Case-2: *Operation with nonlinear loads*

In this example study, nonlinear loads at PCC with the profile illustrated in Fig. 12 (a) are investigated. The adjusted nonlinear currents will be injected through the inverter by the suggested controller to lessen the nonlinear influence on the grid. As a result, grid currents can be sinusoidal and harmonic-free. Figures 12(b) and (c) illustrate the corresponding inverter and grid currents. This may be accomplished by using an inverter controller as an active power filter.

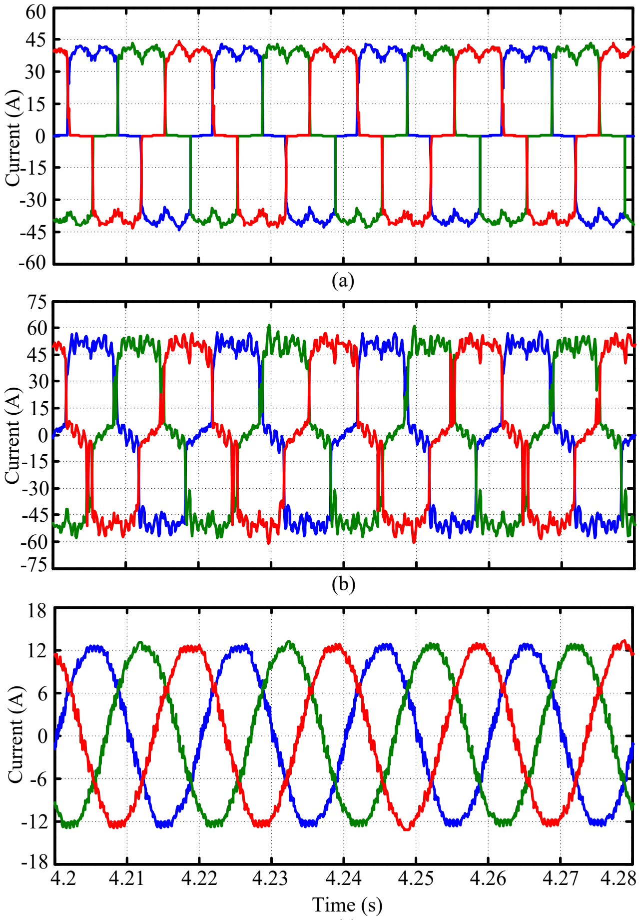

Fig. 12: Currents (a) Non-linear load, (b) inverter, (b) Grid.

Case-3: *Control of inverter controller with reactive power load:*

Majority of loads operated in a distribution consume reactive power, hence substations must compensate reactive power like a DSTATCOM device. However, the suggested controller can assist in compensating reactive power requested by the inverter at load. As a result, the suggested controller's performance is evaluated for reactive power loads linked at load bus. To compensate for the reactive power required by the load at the PCC, the reactive power must be routed through the inverter. The control of inverter is intended to compensate for reactive power at the PCC by adjusting the RMS voltage at the PCC. As a result, reactive power adjustment is possible. The reactive power of 80.0kVAR at PCC at t=2.0sec is considered for testing in this situation, as illustrated in Fig. 13. It is discovered that the inverter is providing the reactive power required by the load. As a result, during steady state, the reactive power supplied by the grid becomes zero.

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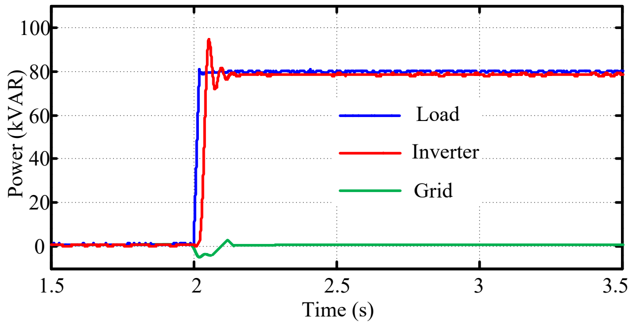

Fig. 13: Various reactive powers.

5. Conclusion

In this research, a novel control method contains TSK-based controllers is constructed for a single stage grid-integrated PV plant. Using the suggested controller, the inverter may also function as an MPPT circuit for the PV unit. A 1.0MW PV system with a capacity of 1.0MW is implemented & tested in different scenarios. The suggested controller can adjust for reactive power requested by local loads, attenuate harmonics caused by nonlinear loads, and provide balanced grid currents in the presence of unbalanced loads. As a result, additional converters are not necessary to manage power quality for local load, and the suggested technology can aid in grid quality supply. For displaying results, the HIL is implemented utilizing two OPAL-RT modules.

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