# Modeling and Simulation of DIGSILENT-based Micro-grid System

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***ABSTRACT:*** *The accurate modeling of micro-grid access to power system planning and design stage needs is the primary problem to solve. This paper modeled the micro grid photovoltaic power generation system, including silicon solar cell, photovoltaic inverters, battery energy storage system, and the micro power distribution system. In the use of power system analysis software (DIGSILENT) of actual power system simulation, the simulation results verify the model's correctness. In the power grid fault disturbance, the light intensity of disturbance and the load disturbances, the simulation results show that the optical storage combined with micro network has fast dynamic response characteristics, and its network of grid-connected voltage influenced by the changes of the light and load is little, while more affected by the network fault influence.*

**Categories and Subject Descriptors:**
**C.2.1 [Network Architecture and Design];** Network Communications; **I.6.5 [Simulation and Model Development]**; Modeling Methodologies

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**Keywords:** Micro Grid, Silicon Solar Cell, Photovoltaic Inverter, Battery Energy Storage System

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## 1. Introduction

With the increasing depletion of conventional energy sources and environment deterioration, the development of the clean energy has become the important strategic task in our country to solve the problem of the shortage of energy and protect environment. Represented by photovoltaic power, the distributed clean energy has the particularity that less pollution, high reliability, and high efficiency of energy utilization. At the same time distributed energy access to power grid brought negative effect; the power fluctuation of the photovoltaic, wind power and other intermittent energy cause problems of electric energy quality. In order to reduce the impact that brought by the distributed energy simple parallel operation on the power grid to the user, reducing its access to the electric energy quality and other aspects of the impact, micro power grid is considered into the research field of intelligent distribution network. Micro grid system modeling is a micro power grid operation analysis, model includes the following parts: the photovoltaic power generation systems, battery energy storage system and a micro grid distribution system [1, 2].

## 2. Photovoltaic power system modeling

Photovoltaic grid-connected generation system consists of a photovoltaic array, the inverter and controller, inverter photovoltaic cell is produced from the power inverter into sinusoidal current injection system; the controller tracks the photovoltaic maximum power point to control the grid-connected inverter's current waveform to the network to transmit power and photovoltaic array maximum power phase equilibrium. The controller is composed of a single-chip microcomputer or general digital signal processing chip as core components; voltage source inverter is mainly composed of power electronic switching devices connected inductor, a pulse width modulation form to the power transmission grid. Typical photovoltaic grid-connected system structure diagram includes: photovoltaic array, inverter and integrated control protective device [3, 4], as shown in figure 1.

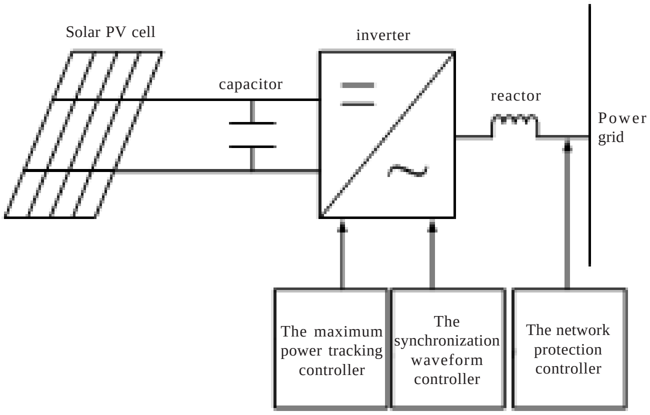


Figure 1. The structure of photovoltaic paralleled in system

Figure 1 shows, the inverter is the core of photovoltaic grid-connected generation system, the maximum power tracking controller and a synchronization waveform controller belong to the inverter part, so the whole modeling work can be divided into three parts: the solar photovoltaic cell model, grid connected control model and network protection control model .

### 2.1 Silicon solar cell model

Silicon solar cell belongs to semicon photoconducting device, sunshine radiation generates electricity. According to electron theory, the character of silicon solar cell can be described by a equivalent circuit, as shown in figure 2.

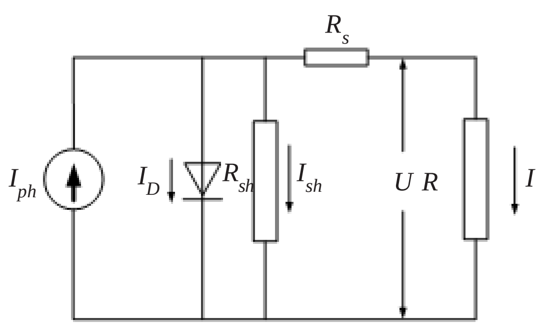


Figure 2. Solar battery equivalent circuit

According to the reference direction of current and voltage,the nonlinear IV characteristic equation can be ejected:

$$I = I_{ph} - I_D - I_{sh} = I_{ph} - I_0 (e^{q(U+IRs)/(AkT)} - 1) - \frac{U + IRs}{R_{sh}} \quad (1)$$

in which:

$I_0$- reverse saturation current, the algebraic sum of hole current of minority current carrier and electron current that passing the P-N node in darkness;

$U$ - the terminal voltage of equivalent diode

$q$ - quantity of electricity

$T$ - the absolute temperature of silicon solar cell

$k$ - boltzmann constant

$A$ - diode curve factor

$R_s$ - in-line equivalent resistance

$R_{sh}$- in-bridge equivalent resistance

Expression (1) is the basic analytic equation derived from physical theory, which can describe the I-V character of general active state, and extensively used in theory analysis.

### 2.2 Standard test environment of the silicon solar cell engineering simplification model

A simplified nonlinear mathematical model:

$$I = I_{sc}.\{1 - \alpha [e^{\beta.U} - 1]\} \quad (2)$$

$$\alpha = I_0 / I_{sc} \quad (3)$$

$$\beta = q / AkT \quad (4)$$

In which: $q$ - electron charge; $T$ - the absolute temperature of solar cell; $k$ - the Boltzmann constant; $A$-- diode curve factor; $I_0$ - reverse saturation current; $I_{sc}$ -- short circuit current; $U$ - equivalent diode voltage;

$\alpha$ and $\beta$ as unknown parameters, can be represented by the following method:

The formula (2 ) into a voltage expressions, available:

$$V = \frac{1}{\beta} \cdot \ln \frac{(1+\alpha).I_{sc} - I}{\alpha.I_{sc}} \quad (5)$$

In the maximum power point, $I = I_m$, $U = U_m$ in the open state, $I = 0$, $U = U_{oc}$.

$U_{oc}$- the open-circuit voltage; $I_m$ - maximum power point current; $U_m$ - maximum power point voltage; $P_m$ - maximum power;

Substituted into type (5)

$$U_m = \frac{1}{\beta} \times \ln \frac{(1+\alpha).I_{sc} - I_m}{\alpha.I_{sc}} \quad (6)$$

$$U_{oc} = \frac{1}{\beta} \times \ln \frac{(1+\alpha)}{\alpha} \quad (7)$$

Considering the normal temperature condition, $\alpha < 1$, can be solved:

$$\alpha = \left[\frac{I_{sc} - I_m}{I_{sc}}\right]^{\frac{U_{oc}}{U_{oc} - U_m}} \quad (8)$$

$$\beta = \frac{1}{U_{oc}} \times \ln(\frac{1+\alpha}{\alpha}) \quad (9)$$

Therefore, based on the 4 electric parameters ($U_{oc}$\ $I_{sc}$\ $U_m$\ $I_m$ ) provided by the manufacturers, the $e$ nonlinear mathematical model can be created. or as long as the use of manufacturers to provide 4 electric parameters , according to type (8) and (9) to derive parameters and, again by type (2) can be obtained by the IV characteristics of solar cell. In this paper, based on the DIgSILENT simulation platform controlled DC current source established the arbitrary intensity and temperature of the silicon solar cell engineering simplification model.

In order to verify the accuracy of the model, the simulation results with the photovoltaic battery and the parameters (such as shown in Table 1) provided by the manufacturers are consistent [7, 8].

| Type | STP180S-24/Ad |
|---|---|
| $U_{oc}$ | 44.8V |
| $U_m$ | 36V |
| $I_{sc}$ | 5.29A |
| $I_m$ | 5A |
| $P_{max}$ | 180Wp |

Table 1. The technical parameter of STP180S-24/Ad 125 single-crystal silicon photovoltaic module

Taking the day illumination 1000W / m2, component temperature 25 DEG C, using the *DIgSILENT/PowerFactory* simulation tools in the controlled current source can draw a photovoltaic cell IV curve as shown in Figure 3, which shows the simulation results is consistent with the real data ( the best working voltage 36V, the optimal working current peak power of 5A, 180Wp).

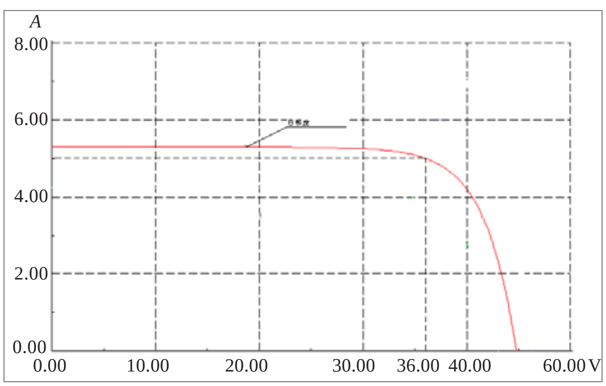


Figure 3. The characteristic curve of 125 single-crystal silicon photovoltaic module

## 2.3 Photovoltaic inverter control model

There Without considering the saturation factor of inverter under the influence of ideal inverter by type (10) simulation:

$$U_{ACd} = K_0 . P_{md} . U_{DC}$$
$$U_{ACq} = K_0 . P_{mq} . U_{DC} \quad (10)$$

In which the $U_{DC}$ is AC voltage, $U_{ACd}$ and $U_{ACq}$ represented the $d$ axis and $q$ axis component respectively. Under the Sine wave modulation, $K_0 = \frac{\sqrt{3}}{2\sqrt{2}}$ , $P_{md}$ and $P_{mq}$ represented Inverter Modulation ratio. The other control point inverters get the modulation ratio as the input of the inverter. In general, the inverter uses the loop current feedback control, according to the outer loop control target to determine the inner loop current feedback control as the reference value, and then through the loop current feedback control to get the modulation ratio. Usually the inverter control objectives are the output active power, reactive power, that is the current-feedback reference value is got by the active and reactive power which was output, as shown in the Figure 4.

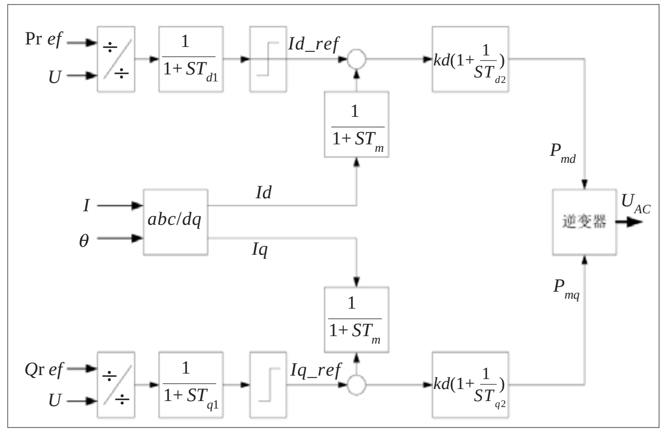


Figure 4. PV inverter control mode

But in the photovoltaic power generation system in the output power of the system is changing with the as the external conditions. When light intensity, temperature change, the controller will take action, adjust the working voltage to the optimal operating point. Therefore the inverter contained controller can get the d axis and q axis component. by the control target $U_{dc\_ref}$ and reference value of reactive power $Q_{ref}$.

## 2.4 Photovoltaic system

Photovoltaic power generation system as shown in Figure 5.

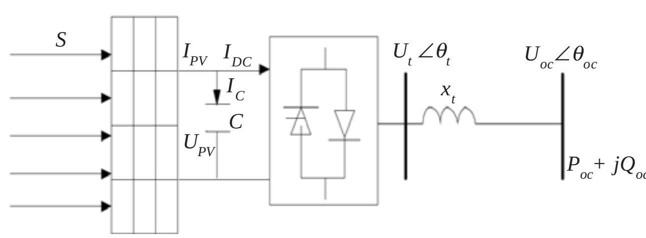


Figure 5. The model of photovoltaic paralleled in system

In the modeling process, think inverter ideal, with power grid connected through reactor.

Photovoltaic array emitted power:

$$P_{PV} = U_{PV} . I_{PV} \quad (11)$$

Photovoltaic power generation system is injected into the communication system for the active:

$$P_{ac} = \frac{U_t U_{ac}}{x_T} \sin(\theta_t - \theta_{ac}) \quad (12)$$

Injected into the communication system for the reactive power

$$Q_{ac} = \frac{U_t U_{ac}}{x_T} \cos(\theta_t - \theta_{ac}) - \frac{U_{ac}^{\ 2}}{x_T} \tag{13}$$

Consider the process of charge and discharge capacitance:

$$P_{PV} = U_{PV} \cdot I_{PV} = C \cdot U_{PV} \cdot \frac{dU_{PV}}{dt} + P_{ac} \tag{14}$$

And separately for voltage source inverter export AC voltage magnitude and phase angle, the inverter control system decision. In addition, the inverter AC / DC voltage is as follows

$$U_t = \frac{\sqrt{3}}{2\sqrt{2}} m \cdot U_{PV} \tag{15}$$

$M$ is modulation ratio, type (11) to (15) that determines the overall model of grid connected interface.

**2.5 Battery energy storage system modeling**

Energy storage battery in micro power network is very important. It is used for optimal power output and stable control of clean energy system and it is possible to adopt the small capacity energy storage, through rapid energy access, realize large power adjustment and rapid absorption of "*saved energy*" or "*power shortage*", thereby improving clean energy system operation stability, improving electric energy quality, enhance the reliability of the system to realize rapid corresponding to power [5-6].

Equivalent circuit model is often used In the field of electrical engineering, detailed energy storage battery equivalent circuit as shown in Figure 6. The open circuit voltage is SOC (important parameters reflecting the battery charged state function), used to describe the dynamic characteristics of the impedance of battery by the internal resistance of the battery and the other resistance.

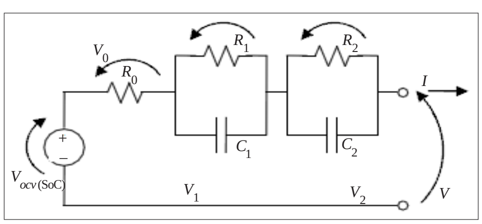


Figure 6. The detailed equivalent circuit of stored energy battery

$$\begin{aligned} V &= V_{OCV}(SoC) - \left( R_0 + \frac{R_1}{1 + sR_1C_1} + \frac{R_2}{1 + sR_2C_2} \right) I \\ &= V_{OCV}(SoC) - R_0 I - \left( \frac{K(1 + sK_1)}{(1 + sK_2)(1 + sK_3)} \right) I \end{aligned} \tag{16}$$

Type (16), in addition to the open circuit voltage, the other parameters and current are nonrelated with *soc*.The table below is a typical model parameters.

| | |
|---|---|
| $R_0$ | 0.07 |
| $K$ | −0.047288 |
| $K_1$ | 597.56 |
| $K_2$ | 32.668 |
| $K_2$ | 1996.7 |

Table 2. The model parameter of LiFeP04 battery typed A123-M1

**2.6 Distribution system modeling with the micro grid**

Electronic systems with micro grid can be modeled considering the characteristic of various parts of it: if there is big difference of each parts, then need to establish practical network topology of the system; if each part contains identical or close characteristics, then establish equivalent network topological structure of the system. Considering the photovoltaic component and the same characteristic of the storage battery used in practical engineering field, usually PV module and storage battery are the same type products with the same manufacturers. The characteristics of the Micro power grid load are almost the same. This paper established micro grid electronic equivalent system model, the photovoltaic power generation system, an energy storage battery system adopt centralized equivalent model, micro grid load characteristics near the same load with General Load-2 said, General Load-1 said other loads, the load characteristics and size can be in the simulation according to requirements set.

## 3. Simulation analysis of the micro grid dynamic response

On the basis of the accuracy of the module, this paper focuses on the analysis of the output power, voltage and current of the network under some extreme conditions: network fault disturbance and no energy storage. The main power grid considering fault disturbance, light load disturbance, three case. In electronic system with equivalent topological structure of the network environment as follows: Simulation of fault disturbance simulation, light intensity disturbance simulation and load disturbance simulation.

**3.1 Grid fault disturbance**

Figure 7 shows an example system equivalent network diagram.

Adoption of the equivalent network shown in Figure 6, assume that the connection line between microgrid and main grid L1-10 in 1.1s fault, 1.3s three-phase short-circuit fault clearance. Micro grid load for the pure active load 0.2MW. Photovoltaic power generation system with maximum power point tracking, control model, which is equal to 0. Energy storage system using PQ control, in which active power reference value is set –0.2MW, reactive power reference value is set 0. Under the power system fault disturbance, the dynamic response characteristics

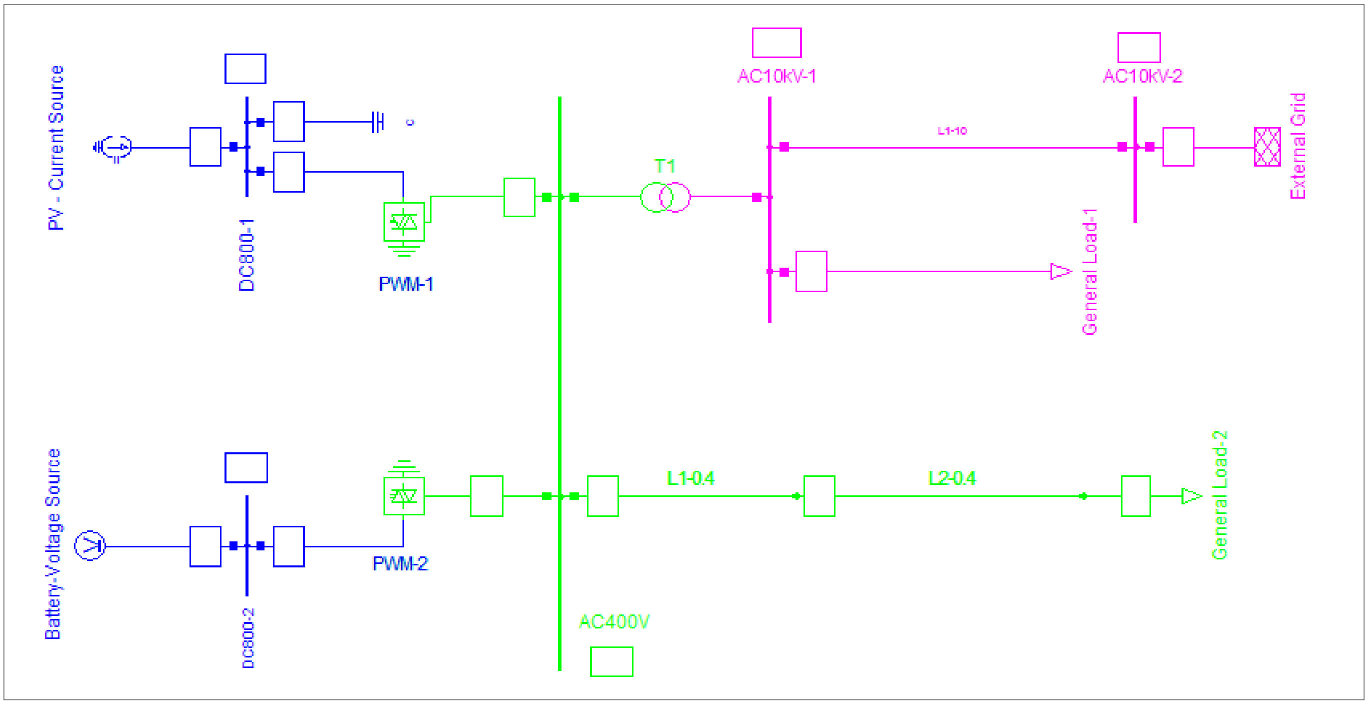


Figure 7. The topological diagram of equivalent network of distribution subsystem

of the active power and reactive power of the photovoltaic power generation system is shown as the Figure 8 and Figure 9:

### 3.2 Light intensity disturbance

Power generation system initial working light intensity of 1000W / m2 conditions, a time of light intensity jump to 900W / m2, as shown in Figure 12.

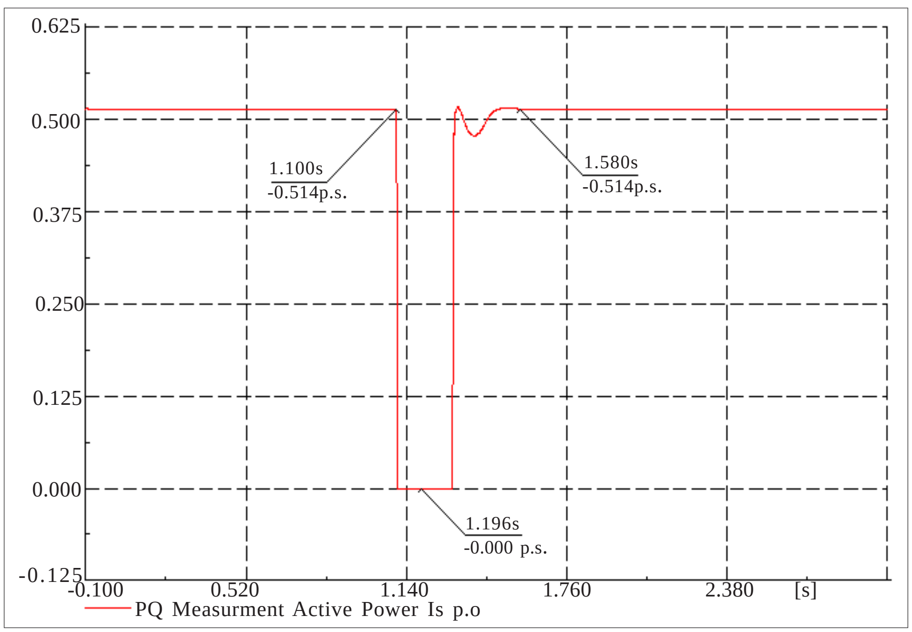


Figure 8. Dynamic response characteristics of active power of photovoltaic power generation system (based 1MWA)

Under the power system fault disturbance, the dynamic response characteristics of network voltage and current shown as in Figure 10 and Figure 11:

Figure 10 shows and network voltage failure fault during 0.374 p.u, and network voltage fluctuations down to 0.012 p.u, fault after excision and network voltage restored to 0.374 p.u. and this is the qualified level [7]. The same analysis methods can be used in Figure 11.

The Figure 12 shows the equivalent network, photovoltaic power generation system in light intensity disturbance conditions, and the dynamic response characteristics of the active power and reactive power of the photovoltaic power generation system is shown as the Figure 13 and Figure 14: the dynamic response characteristics of network voltage and current as shown in Figure 15 and Figure 16:

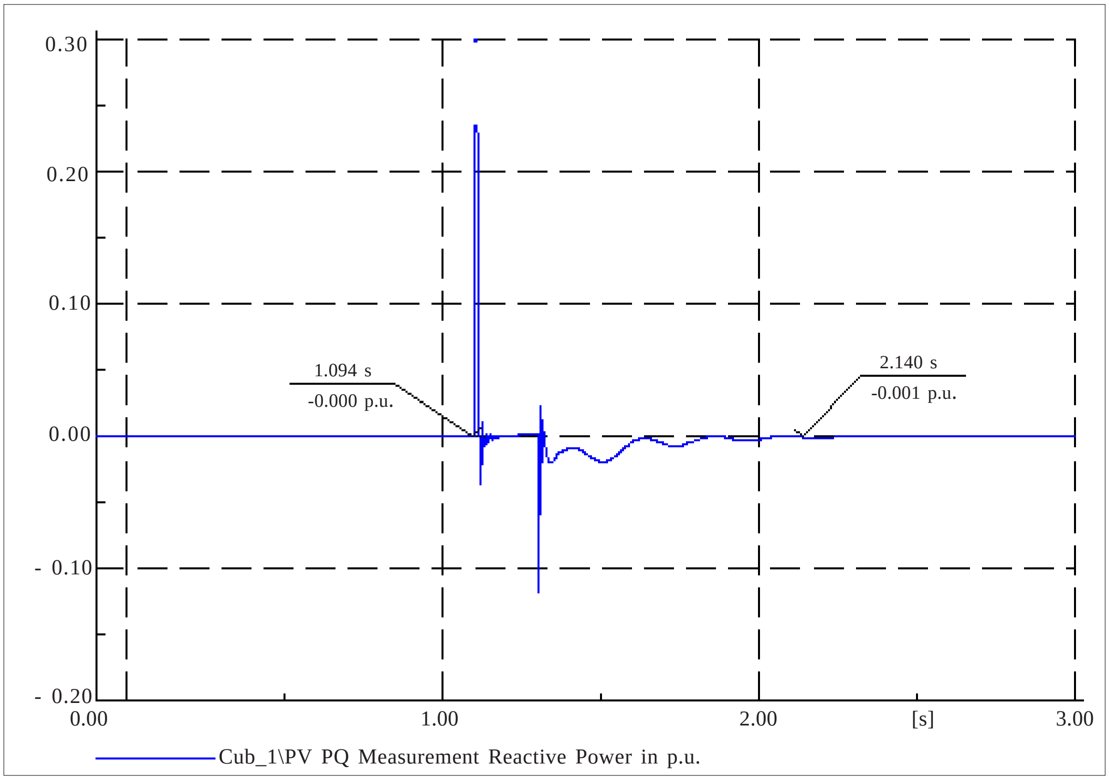


Figure 9. Dynamic response characteristics of rective power of photovoltaic power generation system (based 1MWA)

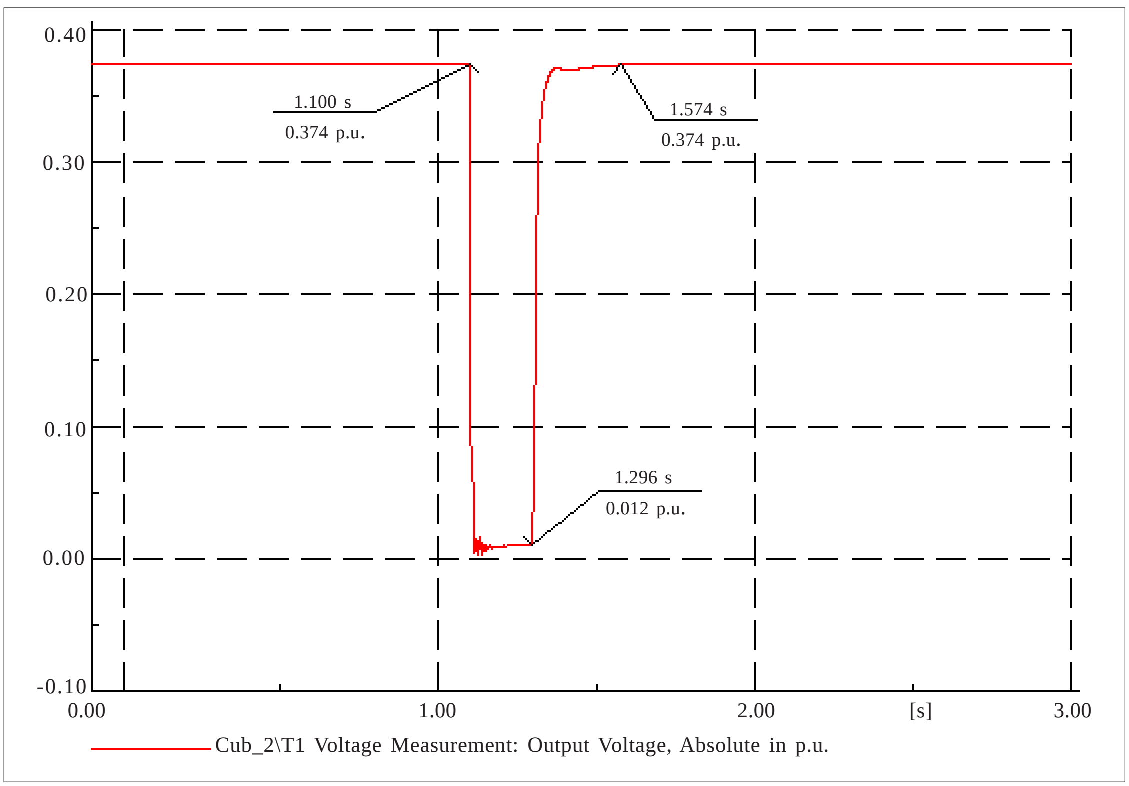


Figure 10. The voltage dynamic response of parallel point (based 1kV)

Figure 15 shows before the light intensity mutation the network voltage was in 0.374 p.u, after the light intensity mutation the network voltage is fluctuations down to 0.366 p.u. The same analysis methods can be used in Figure 16.

### 3.3 Change of load disturbance

A micro power grid in the initial loading of 300kW, in the 1.1s step in increments of 20%, this time and network voltage response characteristics as shown in Figure 16 (red, blue line as to load and network voltage):

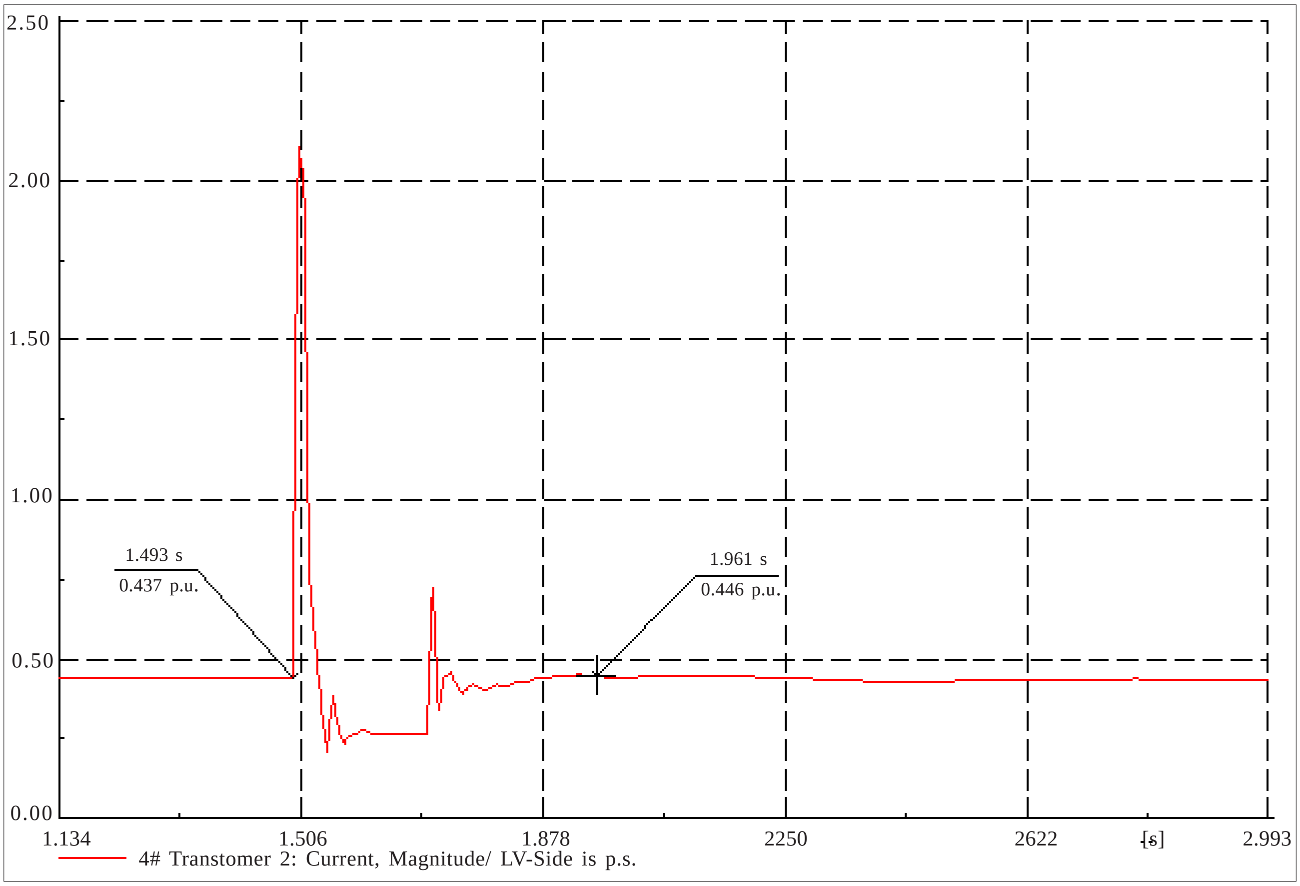


Figure 11. The current dynamic response of parallel point (based 1kA)

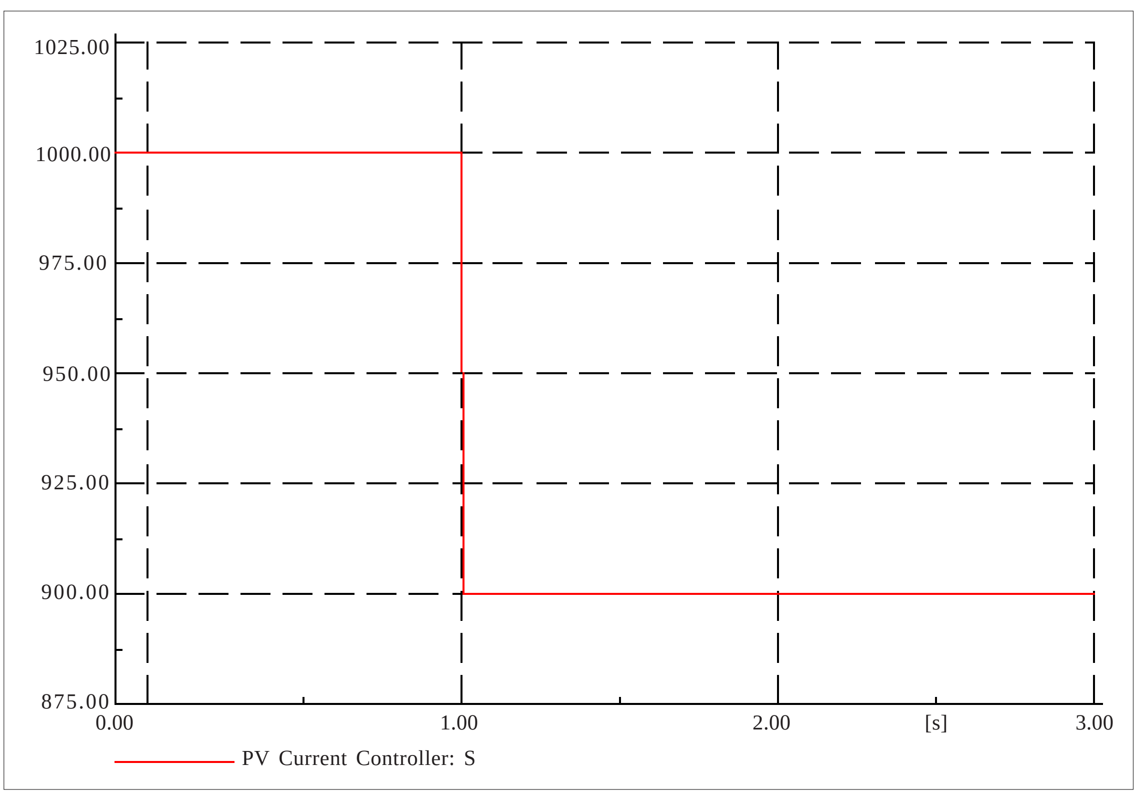


Figure 12. The step change of intensity of illumination

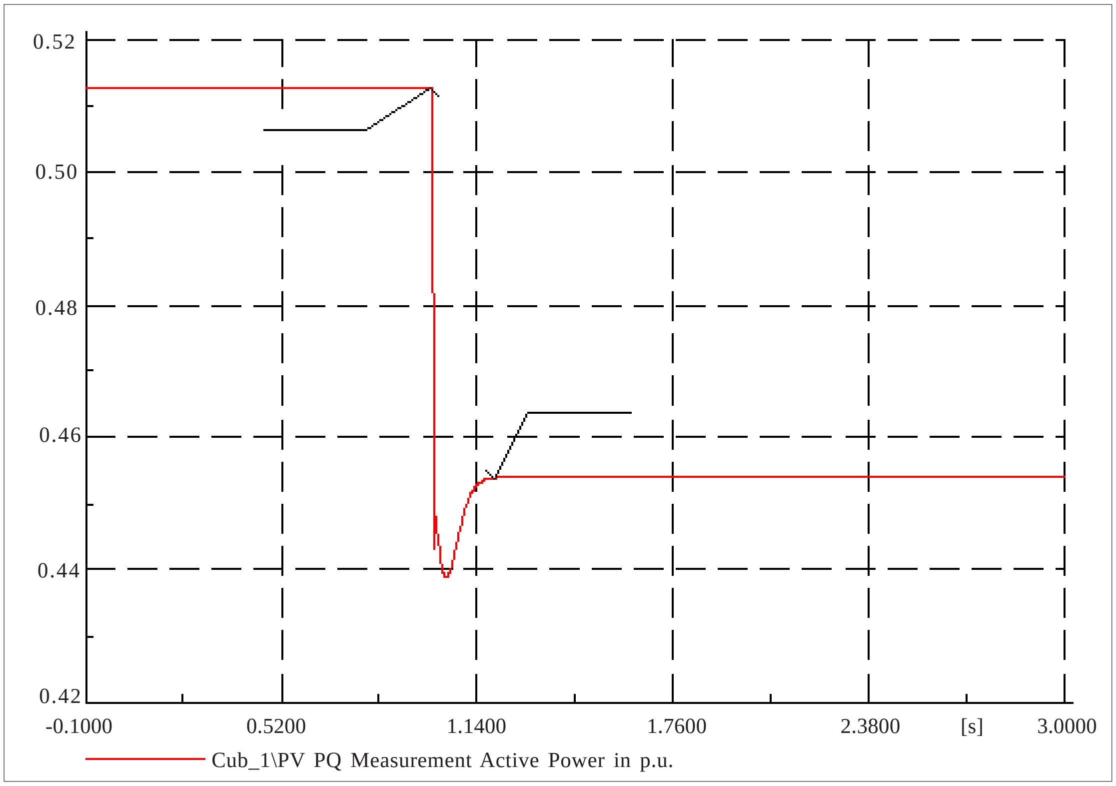


Figure 13. Dynamic response characteristics of active power of photovoltaic power generation system (based 1MWA)

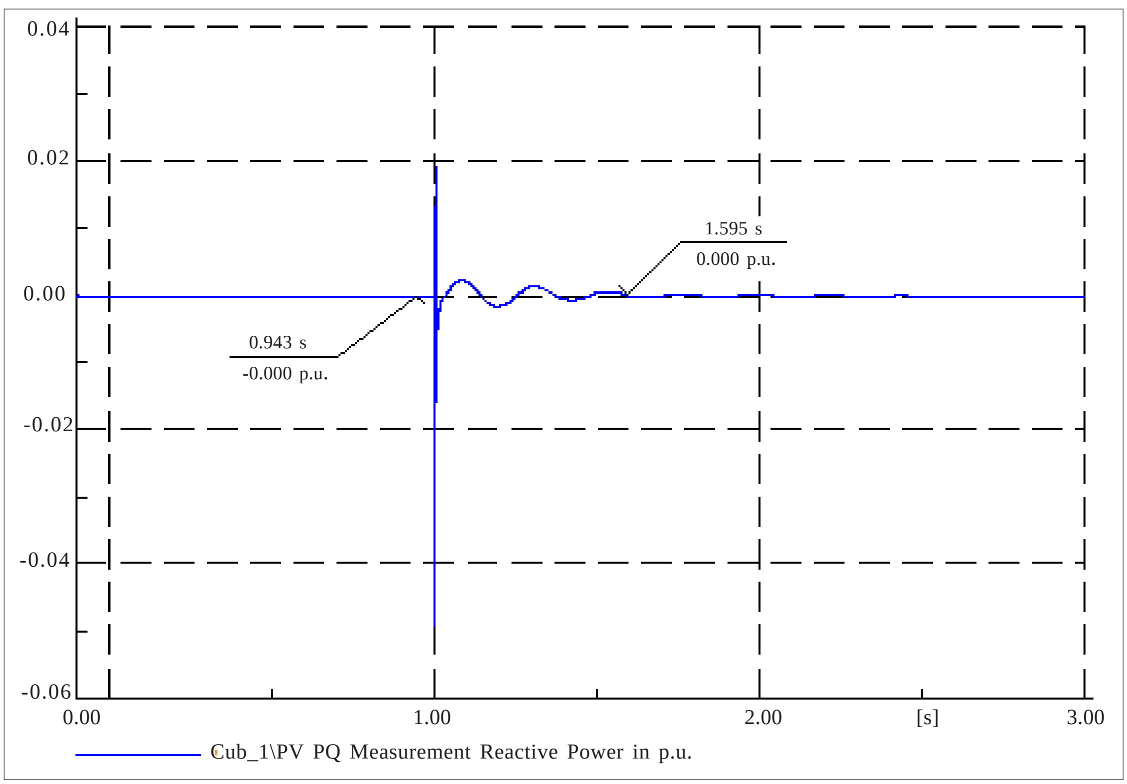


Figure 14. Dynamic response characteristics of rective power of photovoltaic power generation system (based 1MWA)

Figure 16 shows that the votage almost no floating l when the load increments of 20%.

**4. Conclusions**

This paper based on the DIGSILENT simulation platform controlled DC current source established engineering simplification model for arbitrary intensity and temperature of the silicon solar cell, photovoltaic inverters, battery energy storage system, and electronic system with micro gird. The simulation results show that the model has high

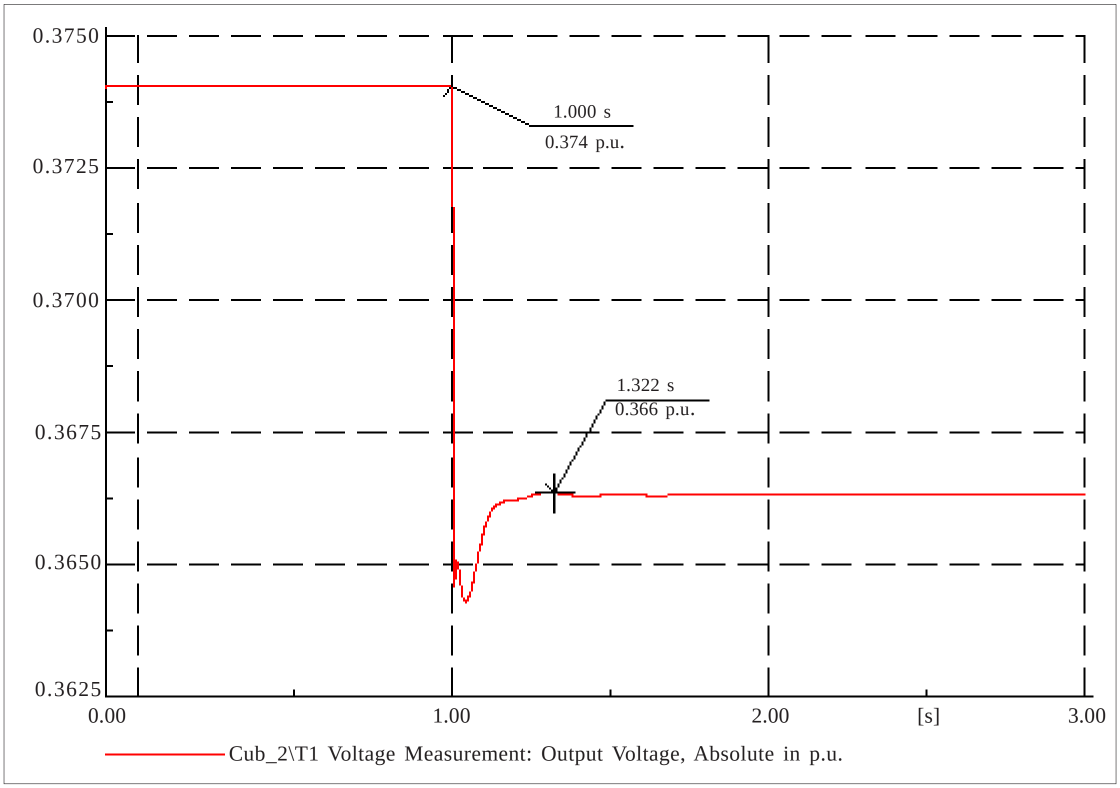


Figure 15. The voltage dynamic response of parallel point (based 1kV)

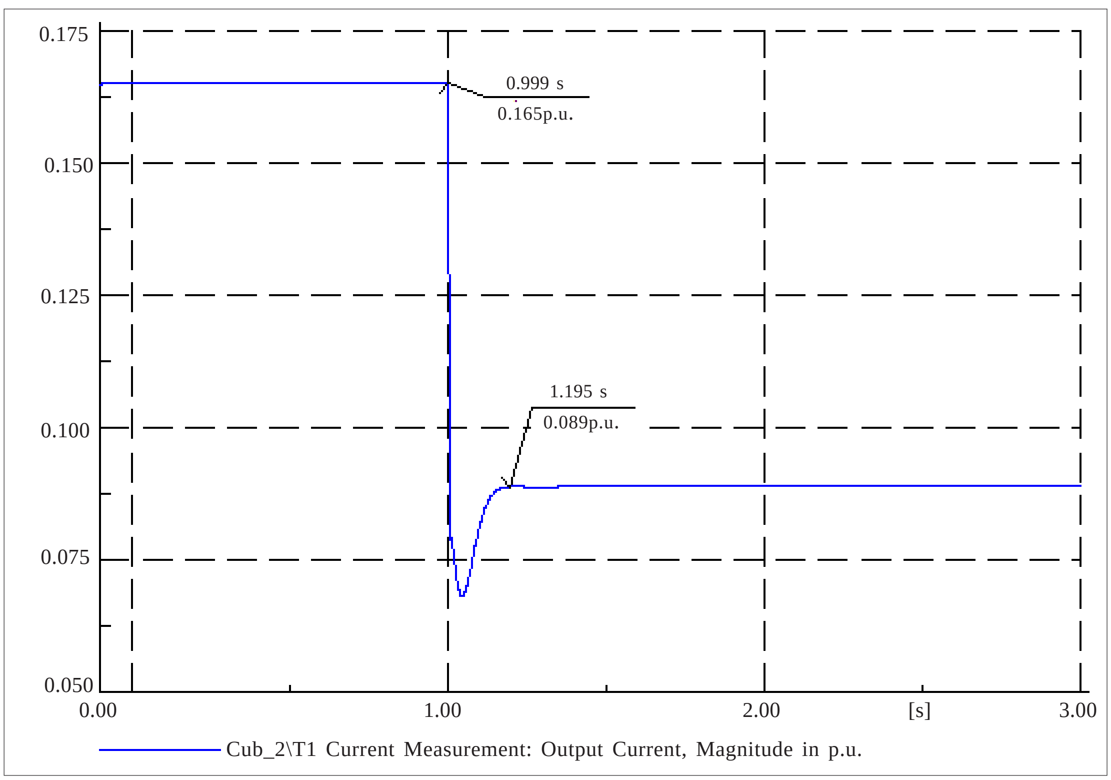


Figure 16. The current dynamic response of parallel point (based 1kA)

accuracy. In power grid fault, illumination variation, mutation load under the conditions of the simulation analysis shows: optical storage combined with micro network with fast dynamic response, both in the disturbance after transient response. The access, in network fault disturbance and network voltage fluctuations; in light and load disturbance, and outlets of the voltage can be maintained in the normal range. The optical storage combined with micro network on power systems voltage by light and the influence of load changes little, affected by the network fault influence.

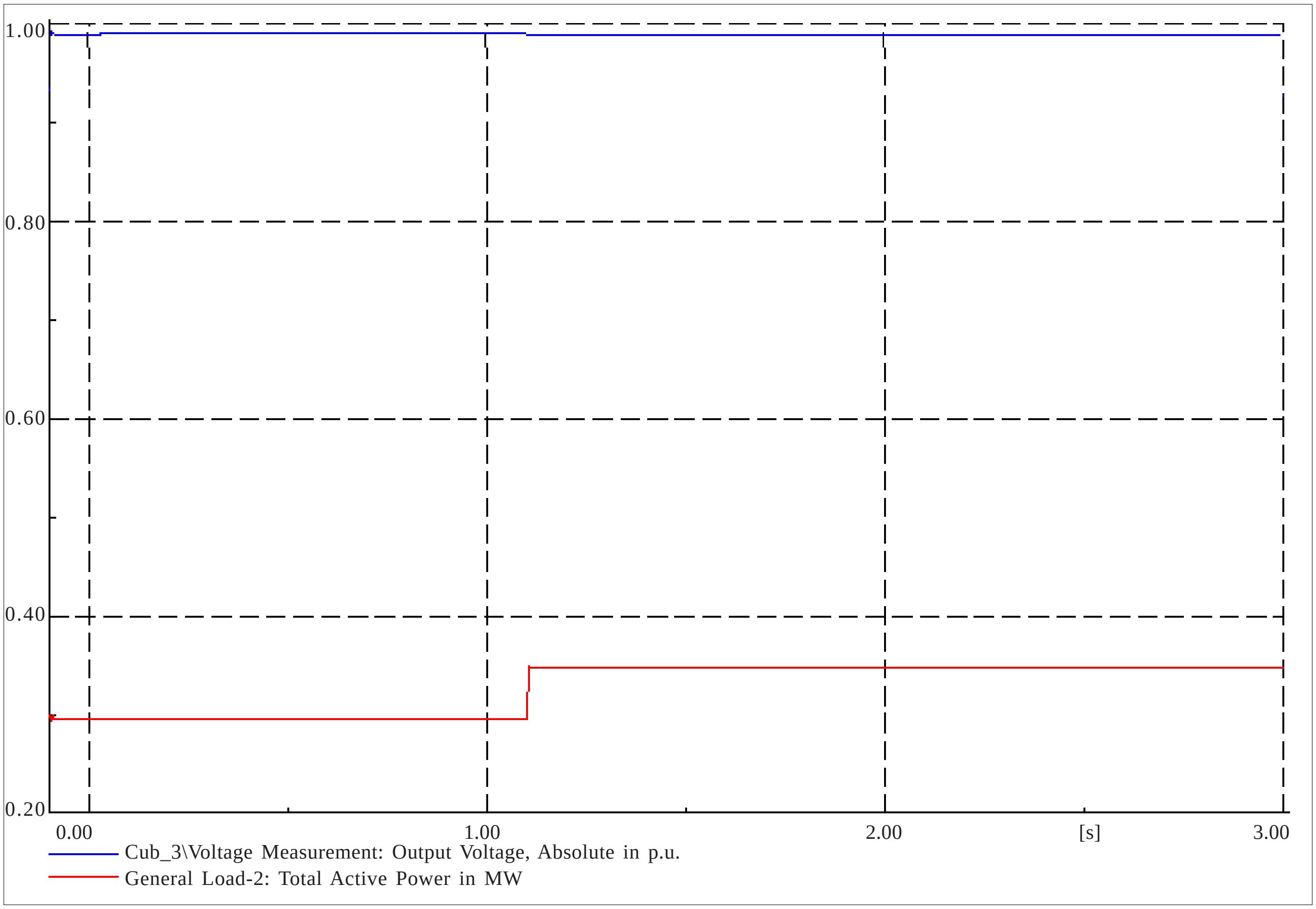


Figure 17. The voltage dynamic response of parallel point (based 1kV)

**5. Acknowledgments**

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