Reliability Evaluation of Software Defined Photovoltaic Energy System

Kai Zheng, Zhe Zhang, Liyou Fang,Yi Song
Taihu University of Wuxi
Jiangsu Key Construction Laboratory of loT
Application Technology
Wuxi , China
534347752@qq.com

Xin Huang
Xi'an Jiaotong-liverpool University
Suzhou , China
zg570419@126.com

***Abstract*—In order to face the challenge of air pollution, renewable energy sources attract more attention. Photovoltaic (PV) energy system is one of renewable energy systems. It has many advantages include: small scaled, no air pollution and so on. However, lack of flexible control of this system weaken the reliability of it. A new architecture, Software Defined PV Energy System (SDPVES) is designed to solve the problem. The users can remotely upload new algorithms to the converters to change the functions of PV energy system. However, how to improve the architecture design of the SDPVES become a challenge. In this paper, Markov models are used to analyze the reliability of different SDPVES architectures. The tool for model checking is PRISM. The influence of different components is analyzed. What's more, the comparison of different architectures is also shown.**

Keywords-Renewable energy sources, photovoltaic (PV) energy system, SDPVES ,probabilistic model checking

I. INTRODUCTION

Renewable energy sources has attracted increasing attention duo to the heavy air pollution all over the world. Renewable energy can solve the problem [1]. For renewable energy, the most widely used one is solar energy. The energy system for solar energy is called photovoltaic (PV) system [2].

However, the reliability of the PV energy system is still a problem [3]. Some PV energy systems are placed on the roof of the buildings. This make the maintenance more difficult. If the PV systems fail, they will cause damage to the power system.

For PV system, many researchers focus on how to enhance the reliability of the PV energy system. Most of them focus on the control algorithms in the converter. In [4], the author gives a power process approach to improve the reliability of the PV energy system. In [5] [6] [7] [8], the authors give different methods for islanding detection. These also improve the reliability of the PV system.

However, the researchers didn't concentrate on the flexible control of the PV system to improve the reliability of it.

In [9], the author gives a new solution to solve the reliability problem of the PV energy system. He designed a software defined PV energy system (SDPVES) to realize remote control and programme. The user can upload new control algorithms to the converter to reset the converter. According to the real time status of the power system, the electricity company can upload new control algorithms to the PV energy system remotely. This remote and flexible control enhances the reliability of the PV system by remote programme and control.

However, how to improve the architecture design of the SDPVES is still a challenge. If the design of the SDPVES can be improved. The reliability of the SDPVES will also be further enhanced. In this paper, we will give out how to evaluate the reliability of SDPVES and optimize the architecture design of it .

The contribution of this paper is shown below:

- In this paper, we will find out the witch factor influence on the reliability of SDPVES most.
- The most reliable architecture of the 3 architectures will be find .
- The strategy for improving the design of SDPVES will be given.

The rest of this paper has 3 parts. In Section 2, framework and PRISM models about are introduced. Section 3 gives the analysis of the experiment results. Finally, section 4 shows the conclusion.

II. MODEL CHECKING SDPVES SYSTEM

A. The framework of SDPVES

The SDDES is base on software defined internet of things (SDIoT). The SDPVES include 6 parts: applications, cloud, local controller, converter, PV panels and DC load. Its high-level overview is shown in Figure 1.

2473-3636/20/$31.00 ©2020 IEEE
DOI 10.1109/DCABES50732.2020.00038

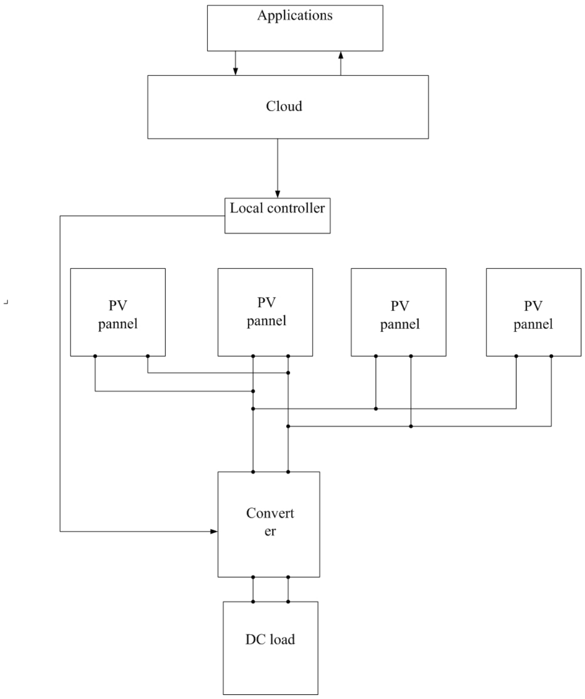

Figure 1. Architecture I

The function of different components is shown as below:

Applications: provide user interface to the users.

Cloud: the new code algorithms can be stored in cloud.

Local Controllers: send the new code and reprogram the converter.

PV Panels: provide energy to the load.

Converters: regulate output voltage.

DC Load: consumes energy

For Architecture II, every PV panel has a converter. The 4 local controllers are connected to the cloud. The distributed SDPVES is shown in Figure 2. In Architecture II,each converter is controlled by a single controller.

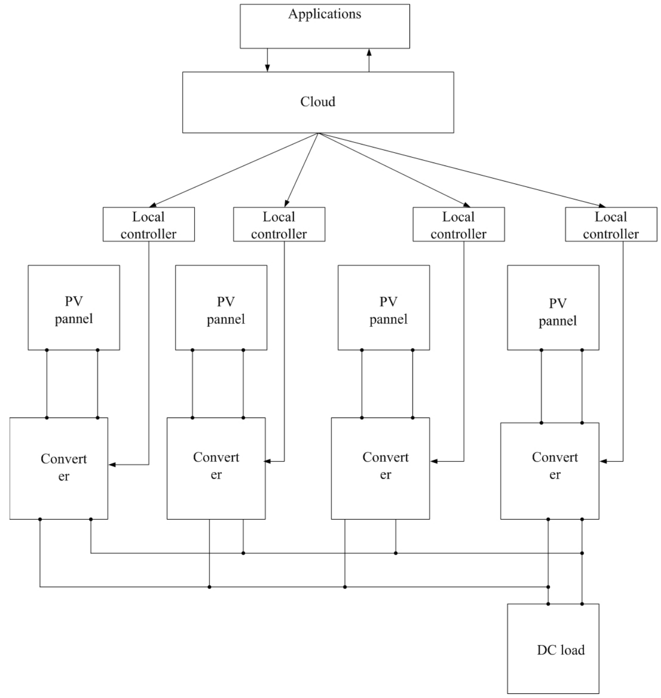

Figure 2. Architecture II

The Architecture III is different from the other 2 architectures. 2 PV panels are connected to an converter. The Architecture III is shown in Figure.3.

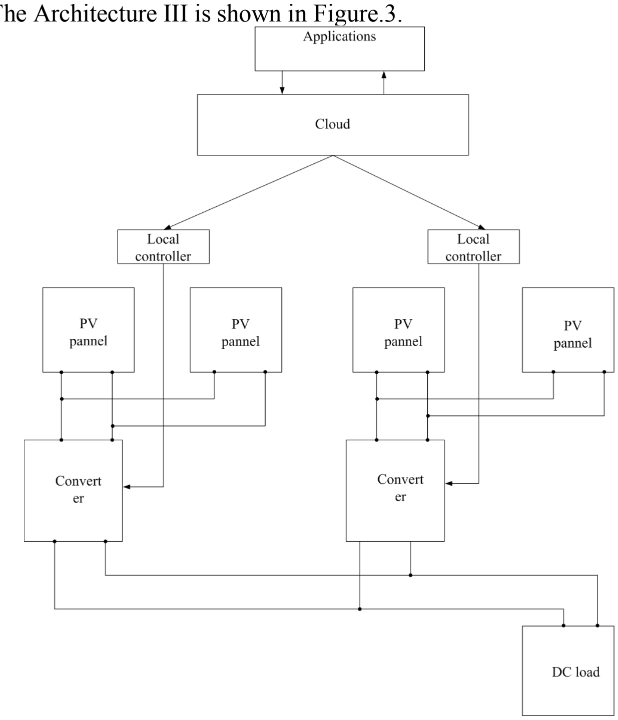

Figure 3. Architecture III

For the 3 architectures, the number of controllers and converters are different. Architecture I has 1 controllers and 1 centralized converter. Architecture II has 4 controller and 4 converters. Architecture III has 2 controllers and 2 converters. The differences are shown in Table 1.

TABLE I. THE DIFFERENCES OF THE 3 ARCHITECTURES

	Architecture I	Architecture II	Architecture III
Application	1	1	1
Cloud	1	1	1
Local controller	1	4	2
PV	4	4	4
Converter	1	4	2

B. *The Markov Models for SDPVES*

The 4 models for the 4 architectures are constructed in PRISM.Take Architecture I as an example , the modeling process is described as follows.

Cloud Layer Module: The initial value for cloud layer is 1 (means cloud layer is ok). If the cloud layer fails with a failure rate “lambda c”, “c” will become 0 (means the cloud layer fail). The code for cloud layer is shown below:

```
c : [ 0 . . 1 ] i n i t 1 ;
[ ] c =1−>c  ∗ lambda c : ( c ’= c −1) ;
```

Local Control Layer Module: The initial workable local controller is 1. Each local controller fails with a failure rate “lambda con”The code is shown below:

```
d : [ 0 . . 1 ] i n i t 1 ;
[ ] d >0 −> d∗  lambda d : ( d’= d −1) ;
```

PV Layer Module: The initial number of applicable PV panels is 4. If each PV panel fail with a failure rate lambda p, “p” will minus 1. The code for PV layer is shown below:

```
p : [ 0 . . 4 ] i n i t 4 ;
[ ] p>0−>p∗ lambda p : ( p’=p−1) ;
```

Converter Layer Module: The initial number of applicable converter is 1. If each converter fails with a failure rate “lambda converter”, “converter ” will minus 1. The code for converter layer is shown below:

```
converter : [ 0 . . 1 ] i n i t 1 ;//number of converter s working
[ ] converter >0 −> converter ∗ lambda p : ( converter ’= converter −1) ; // f a i l u r e of a s i ng l e converter
```

Failure Conditions: we need at least 2 branches of the system are workable, so take architecture I as an example ,the failure condition is shown below:

formula down = (c<1) |(p<2) |(con<1) |(converter <1)

Architecture II, III are similar, but the reliability of the 3 architectures are different. According to the 3 architectures, the failure conditions will be adjusted.

III. TESTING AND ANALYSIS OF RESULTS

The experimental results are explained by analyzing different categories of SDPVES components.

A. *Performance Comparison of Architecture I, II and III*

The models for the 3 architectures are built in PRISM. According to Figure 2. The finding is shown below:

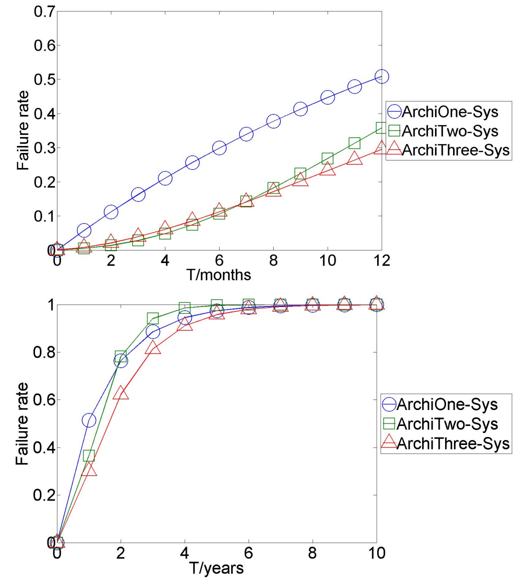

Figure 4. The comparation of the 3 architectures

Finding 1 : Before 6 months, architecture II is the most reliable one. After 6 months, architecture III is the most reliable one .

B. *Influence of Cloud*

After we take the most reliable one architecture III, we can analyse the impact of each component. “2y”means the cloud fails once in 2 years. According to Figure 5. The finding is shown below.

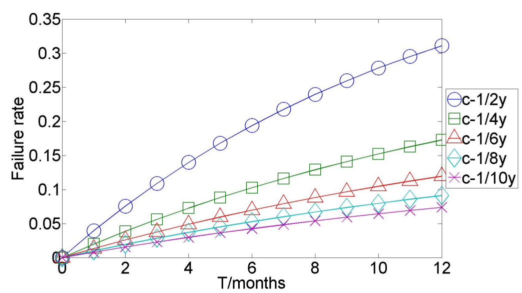

Figure 5. The impact of cloud

Finding 2 : the impact of cloud is very obvious, and the failure rate of the SDPVES is proportional to the failure rate cloud .

C. *Influence of Local Controller*

Next, we analyze the impact of local controller .According to Figure 6. The finding is shown below:

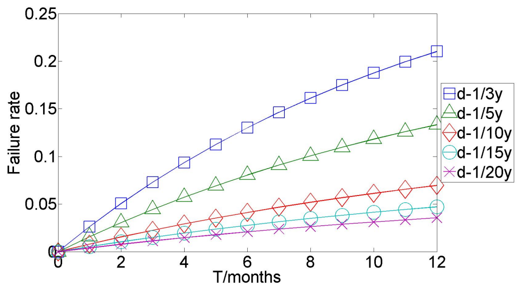

Figure 6. The impact of local controller

Finding 3: the impact of local controller is smaller than cloud , and the failure rate of the whole system is also proportional to the failure rate of local controller.

D. Influence of PV Panels

Finally,the impact of PV panels is analyzed. According to Figure 7. The finding is shown below.

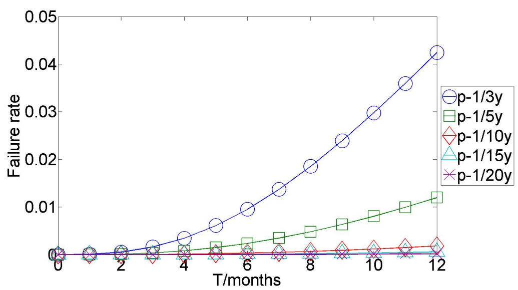

Figure 7. The impact of PV panels

Finding 4: the impact of local PV panels is the least, and the failure rate of the whole system is also proportional to the failure rate of PV panels.

IV. CONCLUSION

In this paper, 3 typical architectures are designed for SDPVES. The reliability of the 3 architectures are analyzed. The influence of each component is also analyzed. We find that architecture III is the most reliable one in long time.What's more, the impact of cloud is the largest.

For further study, the architecture of the SDPVES will be improved to meet different occasions, and the analysis of the new architectures will be conducted in future.

REFERENCES

[1] Tomar A , Shrivastava G . Grid Integration of Renewable Energy Sources[J]. Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering), 2020..

[2] N. R. Tummuru, M. K. Mishra, and S. Srinivas, "Dynamic energy management of hybrid energy storage system with high-gain pv converter," IEEE Transactions on Energy Conversion, vol. 30, no. 1,pp. 150–160, 2015.

[3] P. Zhang, Y. Wang, W. Xiao, and W. Li, "Reliability evaluation of grid-connected photovoltaic power systems," IEEE Transactions on Sustainable Energy, vol. 3, no. 3, pp. 379–389, 2012.

[4] P. S. Shenoy, K. A. Kim, B. B. Johnson, and P. T. Krein, "Differential power processing for increased energy production and reliability of photovoltaic systems," IEEE Transactions on Power Electronics,vol. 28, no. 6, pp. 2968–2979, 2012

[5] A. Pigazo, M. Liserre, R. A. Mastromauro, V. M. Moreno, and A. Dell'Aquila, "Wavelet-based islanding detection in gridconnected pv systems," IEEE Transactions on Industrial Electronics, vol. 56, no. 11, pp. 4445–4455, 2009.

[6] B. G. Yu, M. Matsui, and G. J. Yu, "A correlation-based islandingdetection method using current-magnitude disturbance for pv system," IEEE Transactions on Industrial Electronics, vol. 58, no. 7, pp. 2935–2943, 2011.

[7] Y. Zhou, H. Li, and L. Liu, "Integrated autonomous voltage regulation and islanding detection for high penetration pv applications,"IEEE Transactions on Power Electronics, vol. 28, no. 6, pp. 2826–2841,2012.

[8] S. Dhar and P. K. Dash, "Harmonic profile injection-based hybrid active islanding detection technique for pv-vsc-based microgrid system," IEEE Transactions on Sustainable Energy, vol. 7, no. 4, pp.1473–1481, 2016.

[9] Mao D , Cao X , Han X , et al. Routing Architecture of Software Defined Energy Internet[J]. Iop Conference, 2018, 192.