Research on the Impact of Power Electronics in New Distribution Networks

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Abstract. With the massively distributed energy sources such as solar photovoltaics integrated into the power distribution network, the new generation of distribution systems exhibits significant features such as randomness and volatility. For this, it is necessary to study how to reduce the voltage disturbance of the new distribution system. The relevant research is carried out on the perception of the time distribution of voltage disturbance in the active distribution network and an equivalent circuit model of a new power distribution system is constructed in this paper. Using MATLAB to simulate the voltage disturbance caused by the output voltage of the solar panel after receiving different intensities of sunlight, and improve the relevant circuits. From this to the study voltage perturbations over time, and the regularity of the influence of improved voltage disturbance on the voltage of the node. Finally get the impact that power electronics can have on the distribution network.

Keywords: new distribution network, voltage disturbance, light intensity, improved inverter.

1. Introduction

The access of a high proportion of new energy will bring problems such as voltage overruns and power flow changes to the distribution network. Due to the complex and changeable grid architecture, massive equipment types, huge amount of operating data and uncertainty in power operation, It makes the distribution network's safe operation more difficult.

Problems caused by distributed energy resources that have different degrees of impact, such as: voltage stability, dispatch to the distribution network, relay protection, reliability and other time problems made people's demand for the controllability of the impact of a high proportion of renewable energy re-intervention in the power grid has been greatly improved.

A joint method was proposed by Lassi Aarniovuori et al, which integrated Wigner-Ville distribution and convolutional neural network, to realize the separation of voltage disturbance in multi-scene and multi-node states [1]. Selin Aviyente et al proposed a multivariate analysis between phase amplitude couplings based on the reduction of interference Rihaczek distribution to capture more accurately phase amplitude coupling [2, 3]. Gerard Ledwich et al Indicated when voltage disturbances occur in the distribution network, electromechanical wave propagation exists in the power system as a transient spatial delay for the change of the rotor angle of the generator, and the slowing effect of the control strategy on the propagation speed of the disturbed waveform [4, 5]. Dusabimana E et al Analyze the advantages of μPMU on the basis of the current up-to-date research on μPMU, and their applications in distribution networks [6]. Adedayo Ademola Yusuff et al proposed a framework for identifying weak buses by using the ratio of load bus voltage to standard deviation to mean value, which provides a new idea for the identification of weak nodes [7]. Lalit Kumar et al used Modal analysis PV curves to find the weakest node in the system [8]. Yusuff A.A. et al proposed a method of using the voltage amplitude changed on the load bus to identify a group of weak nodes, based on the simultaneous change of reactive power of all loads [9]. Sekhane H et al used the particle swarm optimization algorithm based on voltage sensitivity to identify the weakest node in the power system by. The "Kessel and Glavitch" voltage stability index was then utilized to help with the best location of reactive power supply [10]. Tiance Zhang et al used PMU amplitude measurement and line reactive power loss benchmark for line parameters to estimate the expression, analyzed the influence of measurement error and line parameter deviation on it and proposed an online detection method of reactive power loss measurement anomaly [11]. Pingfeng Ye et al used the principle of superposition, divided the steady-state circuits for power grids into reactive power disturbance balance circuit and active disturbance balance circuit, and the generator node is broken down into a voltage source and a controlled current source. After converting the two into an equivalence analytic model, the Thevenin's equivalence of PQ perturbation decomposition formed by the superposition of the two can be analyzed [12].

This page combined with the trend of increasing the proportion of distributed new energy power generation in the new distribution network, a solar photovoltaic generator and a voltage disturbance generator are constructed. Through the voltage disturbance generation platform, the voltage disturbance generated by different types of inverter circuits is simulated. The data monitoring algorithm model is constructed to realize the process transformation from voltage data collection to disturbance identification, so as to monitor the voltage disturbance in real time and study the impact and impact on the distribution network caused by voltage disturbance under different circumstances, so as to achieve the research purpose.

2. Theoretical Basis Analysis

2.1. Principle analysis of voltage disturbances

The voltage disturbances are an electrical phenomenon which means the frequency, amplitude, and waveform of the AC power frequency voltage deviate from normal condition. Voltage disturbances is a broad concept, it can be a waveform distortion, or reduced power quality, or the affected power factor within the node.

There is no power supply in the conventional distribution network, the most of it is balance nodes are distributed in the connection nodes of the transmission and distribution network. These nodes' voltage amplitude and phase angle are not interfered with by other factors. Since the traditional distribution networks are mostly radial network topologies, the power is transmitted from the transmission and distribution connection point to the user side, so the voltage is gradually decreasing along the line. The voltage difference between the two ends of the distribution network line satisfies the following relationship:

$$\dot{U}_1 - \dot{U}_2 = \frac{P_2 R + Q_2 X}{U_2} + j\frac{P_2 X + Q_2 R}{U_2} \tag{1}$$

Where U_2 means node2's voltage; P_2 means node2's Active power; Q_2 means node2's Reactive power; R means Line resistance; X means Line reactance.

It can be obtained from the above formula. The line transmits active and reactive power and line parameters that are not affected by the voltage at both ends of the line. Distributed energy resources after they are connected to the distribution grid, this has an impact on the current distribution network system, because it is an external power source, will lead to The return of the power flow and the rise of the terminal voltage. Most of the distributed power sources in the distribution network (such as photovoltaics, micro wind turbines, etc.) use renewable energy to generate electricity, its output is directly related to weather factors such as light intensity and wind speed. In summary, the voltage distribution of a high proportion of new energy distribution network is determined by the distribution network structure, line parameters, load levels of each node and weather factors.

The grid steady-state circuit model can be expressed as:

$$f(P_{Gj}, \left|V_{Gj}\right|, P_{Lj}, Q_{Li}, V_{Lj}, x \mid j = 1...m, i = 1...n) = 0 \tag{2}$$

Where P_L means Active load power; Q_L means Reactive load power; V_L means Load node voltage vector; m means Number of generator nodes; n means Number of load nodes; x means Adjustable amount except P_G and $|V_G|$; f means Grid power flow equation.

When the amount of regulation x changes, Only the structure and parameters of the grid circuit are affected by it. But when the current at the generator node is controlled: $|V_G|$ doesn't change, and it adjusts P_G as the control target value. Using the principle of superposition, the reactive power disturbance balance circuit only considers the node reactive power disturbance and the grid balance control. The steady-state circuit of the power grid is decomposed into reactive disturbance balance circuit and active disturbance balance circuit, its generator node only needs to reflect the characteristics of the voltage source, and the generator node only needs to reflect the characteristics of a controlled current source. Therefore, the active disturbance circuit only considers the active disturbance of the node and the balance regulation of the power grid.

2.2. Mechanism of the solar energy

The solar cell is a device that utilizes the semiconductor materials' photo thermoelectric effect to convert solar energy to electrical energy. The process of the photogenerated volt effect can be simply described as: Supposing there is a beam of light hits the solar cell and its interface layer accept the light, the covalent bonds in both P-type silicon and N-type silicon can have photons with sufficient energy to excite electrons from, this results in the generation of electron-hole pairs. The electrons and holes adjacent to the interfacial layer will be divided by the electric field action of the space charge before they reunite. Electrons move towards the positively charged N-region and holes towards the negatively charged P-region, and output the current.

Many loads nowadays require alternating current, however, the electricity generated by the photovoltaic array with solar photovoltaic effect is direct current. So, inverters are required in the process of converting direct current into alternating current.

2.3. Inverter

The inverter is a type of transformer converts direct current to alternating current, due to the requirements of distribution load balancing and the characteristics of the electrical equipment itself, the inverter with larger capacity generally adopts a three-phase structure, among them, the most widely used circuit is the three-phase bridge inverter as the Figure 1 shown.

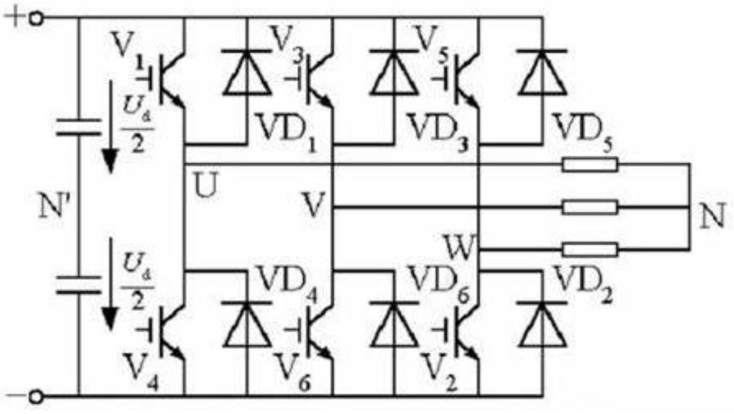

Fig. 1 The inverter (Photo/Picture credit: Original)

The circuit of three-phase bridge inverter is consisted of a DC power supply and three sets of bridge arms, and the load is a star connection. Each bridge arm's upper and lower driving pulses are complementary, and it is a square wave with a 50% duty cycle, that is, the on-time of each switch tube is 180 degrees. According to the designation of the switching device in the figure, its driving signals are 60 degrees different from each other. The three-phase square wave inverter circuit has three switch tubes at any time, and according to specific order sequentially conducted, so there are six conduction modes in a cycle. The line voltages are positive and negative amplitudes, and they are all square waves with a width of 120 degrees and a difference of 120 degrees between the three line voltages.

When the inverter circuit is connected to a pure resistive load, the anti-parallel diodes in all power switches of the three-phase bridge inverter circuit are not conductive, and the inverter draws the pulsation-free DC current from the DC bus. If an inductive load is connected, the inverter also exchanges reactive current with the bus bar, and the DC current ripples at a frequency six times the frequency of the output voltage.

The three-phase inverter square wave circuit has the following characteristics: 1. The output voltage's harmonic content (especially the low harmonic content) is high. 2. The output voltage frequency is adjustable but the amplitude is not adjustable, the corresponding solution is to use phased rectification or uncontrollable rectification followed by a DC-DC converter to adjust the AC voltage output by changing the DC voltage. 3. The DC voltage utilization rate of the square wave inverter circuit is high, and the line voltage amplitude is 1.1 times the DC voltage.

The circuit of three-phase bridge inverter built with LTspice and the waveform of its voltage are shown in the Figure 2 and Figure 3 respectively.

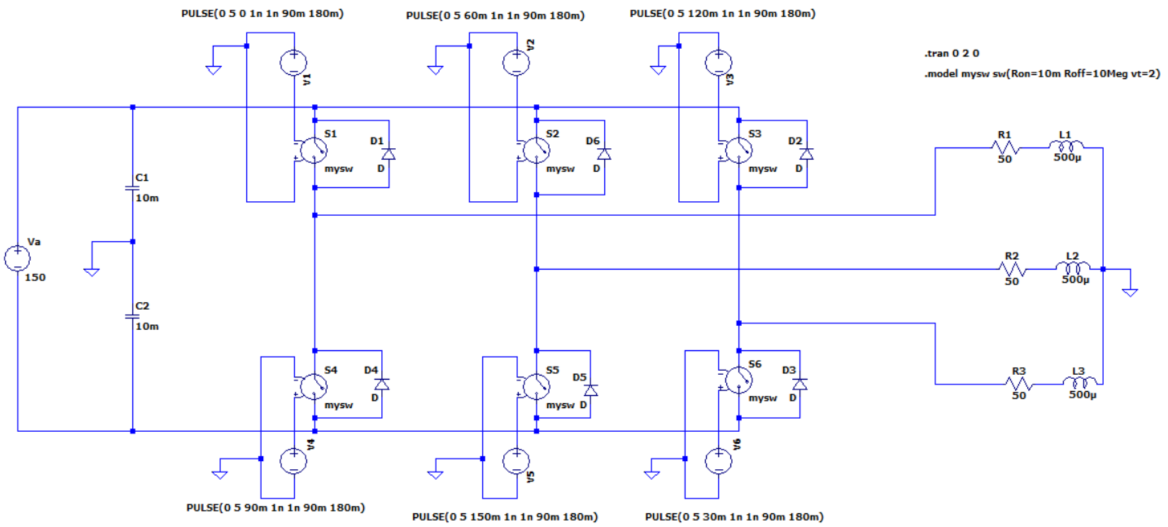

Fig. 2 Three-phase bridge inverter with resistive inductive loads (Photo/Picture credit: Original)

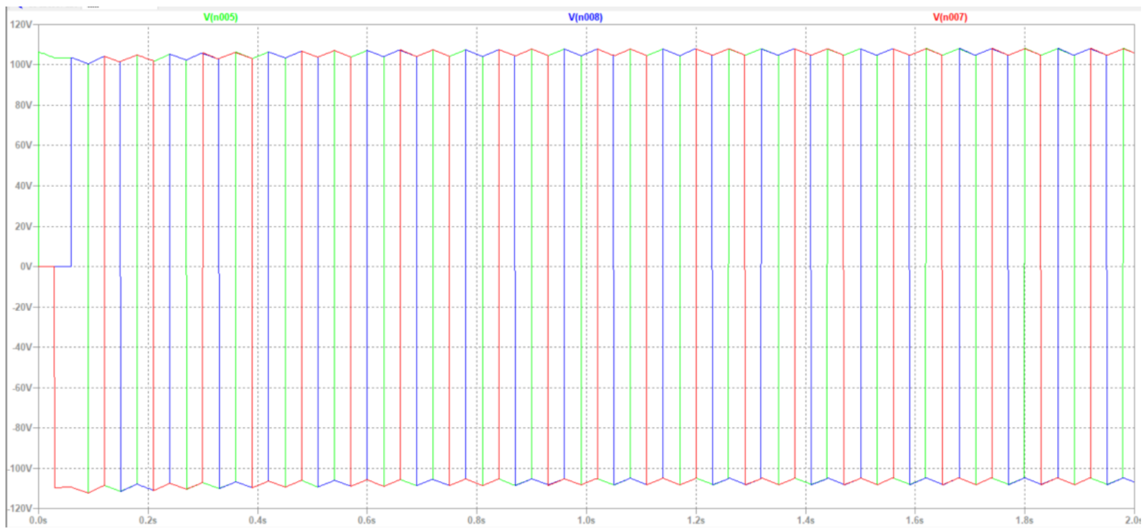

Fig. 3 The original circuit's voltage waveform (Photo/Picture credit: Original)

The improved circuit (increase the capacity of the capacitor) and its voltage waveform are shown in the Figure 4 and Figure 5 respectively.

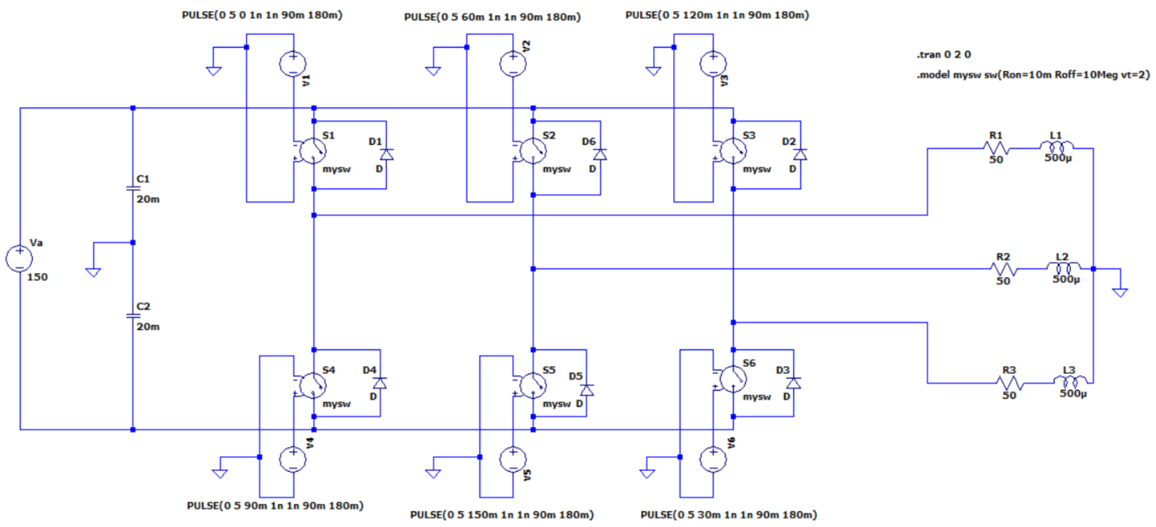

Fig. 4 The improved circuit (Photo/Picture credit: Original)

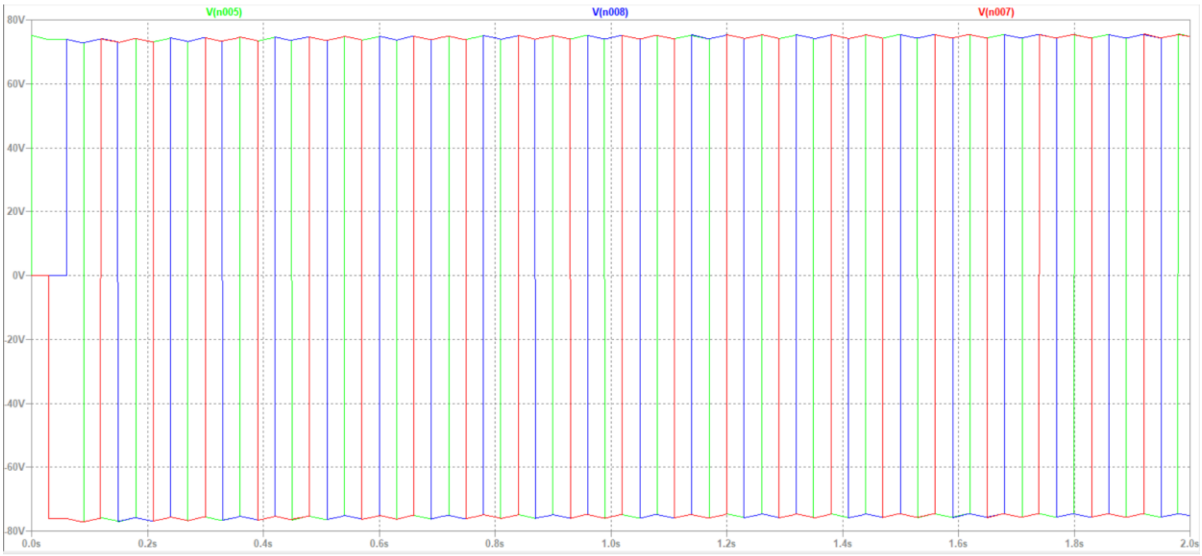

Fig. 5 Improved waveform (Photo/Picture credit: Original)

Comparing the two waveforms, it can be seen that increasing the capacitance can increase the smoothness of the waveform.

3. Simulation analysis

3.1. Principle analysis of voltage disturbances

3.1.1. Solar panel parameters

This paper used the PV array as the Figure 6 shown from the MATLAB as a reference relationship between the light intensity and the amplitude of the output voltage.

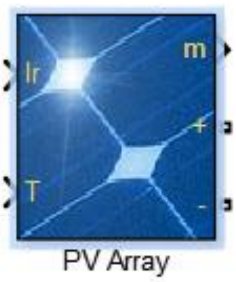

Fig. 6 PV array from the MATLAB (Photo/Picture credit: Original)

The light intensity and the output voltage's relationship curves is shown in the Figure 7 below.

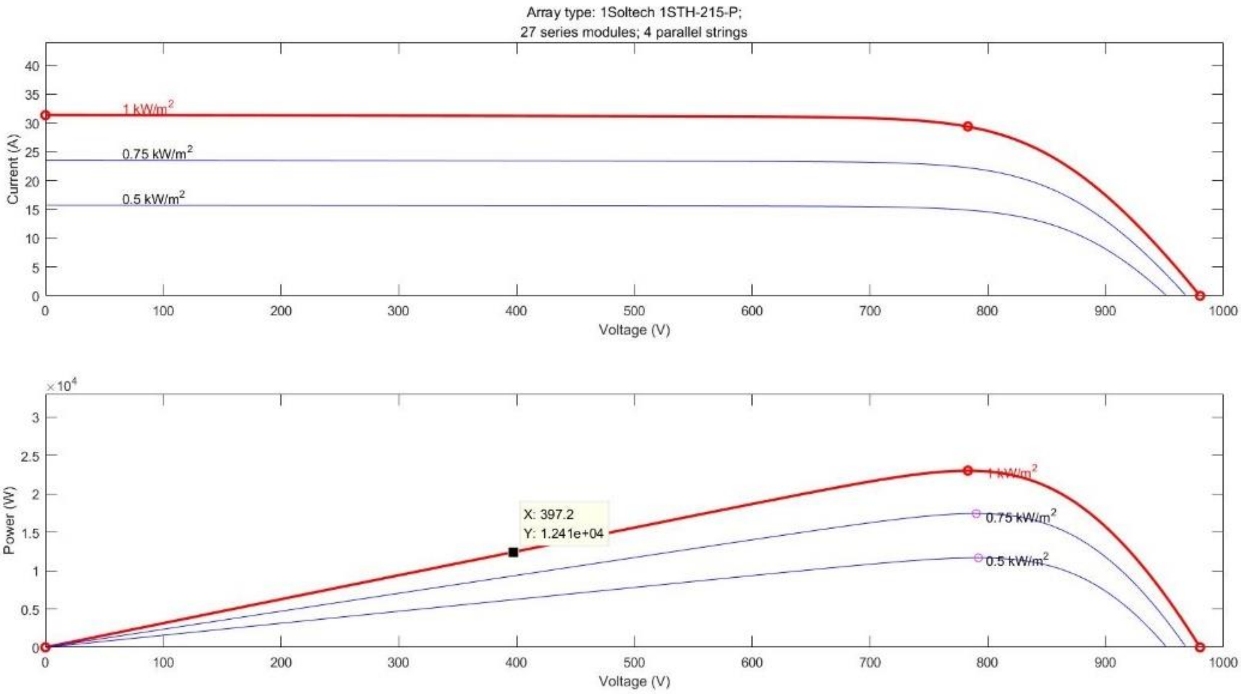

Fig. 7 The light intensity and the output voltage's relationship curves (Photo/Picture credit: Original)

3.1.2. Study system

This Figure 8 shown below is the IEEE 33-node distribution network system with renewable energy units which is used for simulation testing in this paper. Also, this paper used the case33bw example in mat power for simulation

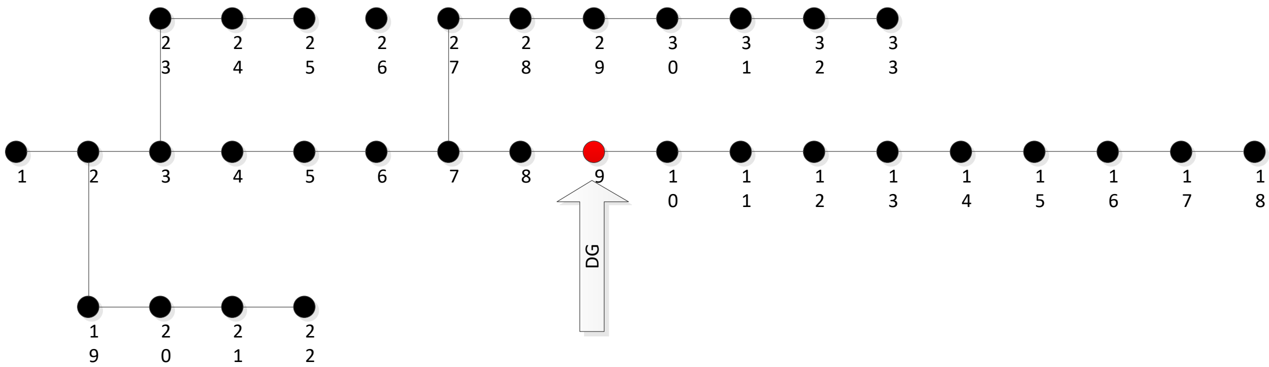

Fig. 8 IEEE 33-node distribution network system (Photo/Picture credit: Original)

Set up a set of sunlight that changes intensity over time, find out the corresponding open-circuit voltage in the comparison table and Input into the inverter as a voltage source. It will be converted into three-phase electricity by the inverter and connected to node 9 and calculate the PV value entered to node 9.

At this time, a 0.75 $kw \bullet m^2$ photovoltaic power supply is used as a voltage source for inverters.

Setting the light intensity =

[0,0,0,0,0,0,0.5,0.7,1,1.1,1.3,1.6,1.5,1.2,1,0.8,0.7,0.4,0,0,0,0,0,0]*10000

Find the corresponding voltage from the table:

[0,0,0,0,0,0,213,298,427,471,557,689,643,514,427,341,298,170,0,0,0,0,0,0]

Input it into the two circuits as the voltage value, and finally find the output PV value of the two circuits respectively:

PV1=[0,0,0,0,0,0,0.1124,0.4435,0.9106,1.1079,1.5495,2.3709,2.0649,1.3194,0.9106,0.5807,0.4435,0.1143,0,0,0,0,0,0];

PV2=[0,0,0,0,0,0,0.1034,0.4085,0.8817,1.6082,1.1435,2.0386,1.8598,1.0155,0.7132,0.4632,0.4653,0.1283,0,0,0,0,0,0];

Connected the output PV to the IEEE 33-node distribution network, and the get the voltage disturbances.

3.2. Case simulation

3.2.1. Original case simulation

The PV value of 24 bits is obtained from the designed light intensity:

PV1=[0,0,0,0,0,0,0.1124,0.4435,0.9106,1.1079,1.5495,2.3709,2.0649,1.3194,0.9106,0.5807,0.4435,0.1143,0,0,0,0,0,0];

The resulting simulation data is shown in the Table 1 below:

Table 1. The voltage rise rate of nodes in different time periods when the circuit is connected to the improved circuit shown as Figure 2 (%)

Node numble	8.am	10.am	13.am	15.am
1	0	0	0	0
2	0.0283	0.0694	0.1259	0.0574
3	0.1800	0.4409	0.8000	0.3644
4	0.2921	0.7158	1.2993	0.5917
5	0.4090	1.0023	1.8199	0.8284
6	0.6637	1.6262	2.9520	1.3442
7	0.7221	1.7688	3.2096	1.4622
8	0.9340	2.2904	4.1625	1.8927
9	0.9404	2.3060	4.1902	1.9057
10	0.9464	2.3205	4.2160	1.9177
11	0.9473	2.3226	4.2198	1.9195
12	0.9489	2.3264	4.2265	1.9226
13	0.9552	2.3417	4.2537	1.9353
14	0.9576	2.3474	4.2639	1.9400
15	0.9590	2.3509	4.2702	1.9429
16	0.9605	2.3544	4.2763	1.9458
17	0.9626	2.3595	4.2854	1.9500
18	0.9632	2.3610	4.2881	1.9513
19	0.0284	0.0694	0.1260	0.0574
20	0.0285	0.0697	0.1264	0.0576
21	0.0285	0.0697	0.1265	0.0577
22	0.0285	0.0698	0.1266	0.0577
23	0.1806	0.4425	0.8030	0.3658
24	0.1819	0.4456	0.8085	0.3683
25	0.1825	0.4471	0.8113	0.3696
26	0.6651	1.6296	2.9582	1.3470
27	0.6670	1.6342	2.9664	1.3508
28	0.6754	1.6547	3.0030	1.3678
29	0.6815	1.6695	3.0294	1.3800
30	0.6841	1.6758	3.0408	1.3853
31	0.6872	1.6834	3.0542	1.3916
32	0.6879	1.6850	3.0572	1.3929
33	0.6881	1.6855	3.0581	1.3933

Figure 9 shown below is the voltage rise rate plotted by the data from Table1.

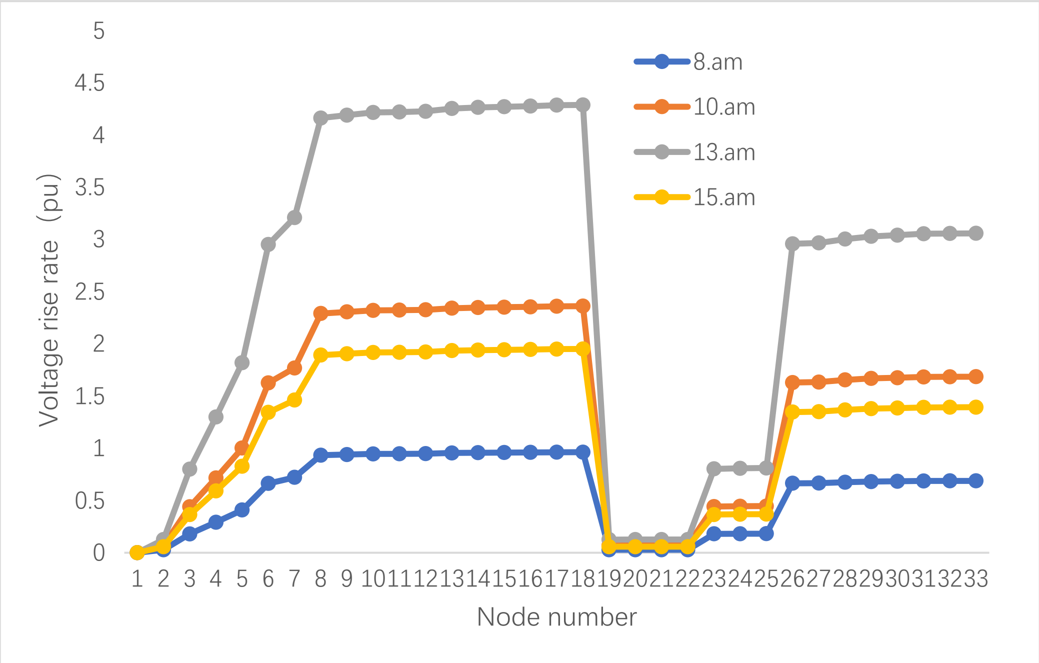

Fig. 9 Voltage rise rate of original circuit (Photo/Picture credit: Original)

From the figure, it can be seen that the change in PV output leads to a change in the rate of voltage rise over time.

3.2.2. Improved case simulation

The PV value of 24 bits is obtained from the designed light intensity:

PV2=[0,0,0,0,0,0,0.1034,0.4085,0.8817,1.6082,1.1435,2.0386,1.8598,1.0155,0.7132,0.4632,0.4653,0.1283,0,0,0,0,0,0];

The resulting simulation data is shown in the Table 2 below:

Table 2. The voltage rise rate of nodes in different time periods when the circuit is connected to the improved circuit shown as Figure 4 (%)

Node numble	8.am	10.am	13.am	15.am
1	0	0	0	0
2	0.0258	0.0993	0.1143	0.0450
3	0.1639	0.6309	0.7265	0.2861
4	0.2661	1.0244	1.1798	0.4644
5	0.3725	1.4346	1.6524	0.6502
6	0.6045	2.3273	2.6805	1.0550
7	0.6577	2.5309	2.9146	1.1477
8	0.8507	3.2799	3.7788	1.4853
9	0.8566	3.3020	3.8040	1.4954
10	0.8621	3.3225	3.8275	1.5049
11	0.8629	3.3255	3.8310	1.5063
12	0.8643	3.3308	3.8370	1.5088
13	0.8701	3.3525	3.8619	1.5188
14	0.8722	3.3606	3.8711	1.5225
15	0.8736	3.3656	3.8769	1.5248
16	0.8749	3.3705	3.8825	1.5271
17	0.8768	3.3777	3.8908	1.5304
18	0.8774	3.3799	3.8933	1.5314
19	0.0258	0.0994	0.1144	0.0451
20	0.0259	0.0997	0.1148	0.0452
21	0.0259	0.0998	0.1149	0.0453
22	0.0260	0.0998	0.1150	0.0453
23	0.1645	0.6332	0.7292	0.2871
24	0.1657	0.6376	0.7342	0.2891
25	0.1662	0.6397	0.7367	0.2901
26	0.6058	2.3322	2.6861	1.0573
27	0.6075	2.3388	2.6936	1.0603
28	0.6152	2.3679	2.7269	1.0736
29	0.6208	2.3888	2.7509	1.0833
30	0.6232	2.3978	2.7613	1.0874
31	0.6260	2.4085	2.7736	1.0923
32	0.6266	2.4109	2.7763	1.0934
33	0.6268	2.4116	2.7771	1.0938

Figure 10 shown below is the voltage rise rate plotted by the data from Table 2.

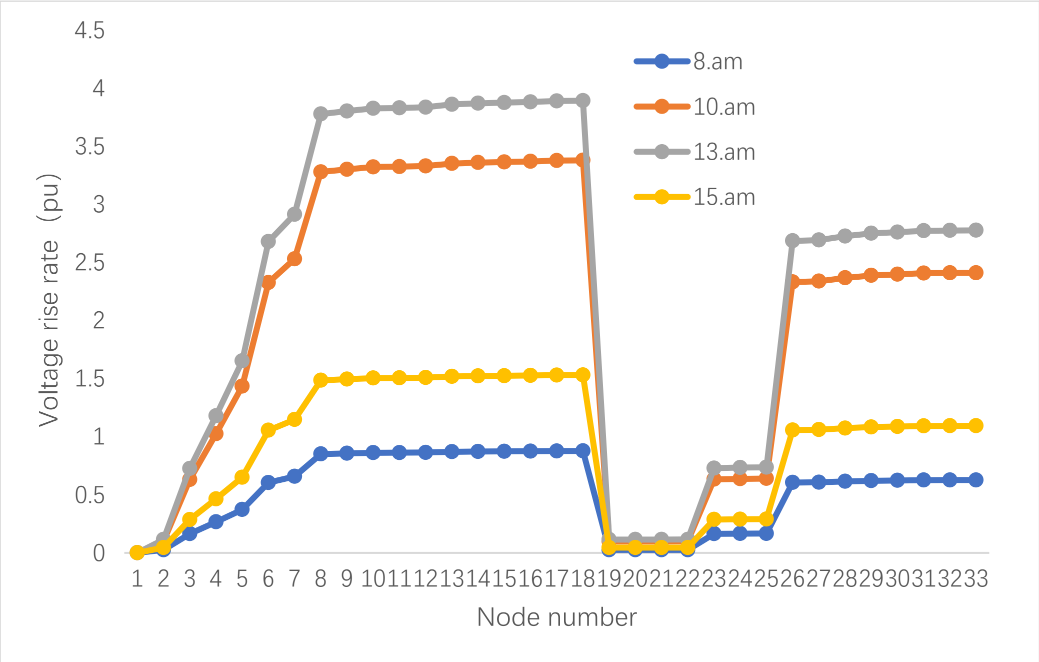

Fig. 10 Voltage rise rate of improved circuit (Photo/Picture credit: Original)

From Figure 10, it can be seen that the change in PV output leads to a change in the rate of voltage rise over time.

3.3. Summary of this chapter

This chapter mainly used a IEEE 33 mlti-node distribution network system, and the characteristics of the output of photovoltaic power generation with the change of light intensity, simulate the inverter output voltage, and input the node to analyze its impact on the power grid.

Comparing the two graphs Figure 8 and Figure 10 shows that the improved inverter circuit will produce fewer voltage fluctuations.

4. Summary

Nowadays, problems such as the difficulty of accurate characterization of power supply quality, the difficulty of two-way voltage over-limit regulation, and the difficulty of tracing the source of harmonic high-density, wide spectrum, and strong noise are prominent. In this paper, the equivalent simplification of the new power distribution system is carried out, then simulated the voltage amplitude of the output of sunlight intensity under different time conditions, and finally obtain the PV value input into the distribution network. This resulting voltage disturbance can help us study the impact of power electronics on improving the voltage disturbance.

However, this paper only studied the mechanism of voltage disturbance caused by photovoltaic power grid, the impact of other energy storage devices, flexible loads, etc., on the grid is not considered, and because the access of photovoltaic is 24 hours a day, there will be 8-10 hours of non-production, this complicates the results of the study when coupling the voltage disturbances caused by the rest of the distributed power sources. Therefore, for further research, the output characteristics of different distributed generators can be studied and their coupling characteristics can be analyzed, in this way, a more comprehensive voltage disturbance model of the distribution network is established.

References

[1] Cai K, Cao W, Aarniovuori L, et al. Classification of power quality disturbances using Wigner-Ville distribution and deep convolutional neural networks. IEEE Access, 2019, 7: 119099-119109.

[2] Munia T T K, Aviyente S. Comparison of wavelet and rid-rihaczek based methods for phase-amplitude coupling. IEEE Signal Processing Letters, 2019, 26(12): 1897-1901.

[3] Munia T T K, Aviyente S. Multivariate analysis of bivariate phase-amplitude coupling in EEG data using tensor robust PCA. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 2021, 29: 1268-1279.

[4] Li T, Ledwich G, Mishra Y, et al. Wave aspect of power system transient stability—Part I: Finite approximation. IEEE Transactions on Power Systems, 2016, 32(4): 2493-2500.

[5] Li T, Ledwich G, Mishra Y, et al. Wave aspect of power system transient stability—Part II: Control implications. IEEE Transactions on Power Systems, 2016, 32(4): 2501-2508.

[6] Dusabimana E, Yoon S G. A survey on the micro-phasor measurement unit in distribution networks. Electronics, 2020, 9(2): 305.

[7] Yusuff A A. Voltage stability index based on standard deviation-mean ratio for identification of weak nodes. 2017 IEEE AFRICON. IEEE, 2017: 1255-1259.

[8] Kumar L, Raw B K, Gupta S K, et al. Voltage stability enhancement using shunt devices and identification of weak bus through voltage stability indices. 2019 4th international conference on recent trends on electronics, information, communication & technology (RTEICT). IEEE, 2019: 247-251.

[9] Yusuff A A, Mosetlhe T C, Ayodele T R. Statistical method for identification of weak nodes in power system based on voltage magnitude deviation. Electric Power Systems Research, 2021, 200: 107464.

[10] Sekhane H, Labed D. Identification of the weakest buses to facilitate the search for optimal placement of var sources using "Kessel and Glavitch" Index. Journal of Electrical Engineering & Technology, 2019, 14: 1473-1483.

[11] Zhang Tiance, Wang Jianxiao, Li Geng-yin, et al. Spatial and temporal distribution sensing method of distribution voltage for high proportion new energy access. Automation of Electric Power Systems, 2021, 45(02): 37-45.

[12] Ye Pingfeng, Han Xueshan, Yu Yixiao, et al. Thevenin Equivalence of PQ perturbation Decomposition for Power Grids. Proceedings of the CSEE, 2022, 42(09): 3239-3250.