ASSESSING THE INFLUENCE OF SOLAR POWER PLANT ON THE DISTRIBUTION POWER GRID OF VIETNAM

ĐÁNH GIÁ ẢNH HƯỞNG CỦA NHÀ MÁY ĐIỆN MẶT TRỜI ĐẾN LƯỚI ĐIỆN PHÂN PHỐI TẠI VIỆT NAM

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ABSTRACT

Currently, renewable energy sources integrated into Vietnam's medium-voltage power grid are developing strongly nationwide. Operational reality shows that the integration of renewable energy sources into the distribution grid is causing power quality problems such as overvoltage, increased capacity loss on the grid, and especially negative impacts on power quality to the working of the protective relay system. This article analyzes and evaluates the impact of the Yen Dinh solar power plant in Thanh Hoa, Vietnam when connected to the 22kV power grid such as: reverse power flow, overvoltage, influence of harmonics, changes operational methods for placing economic capacitors and coordinating protection when the plant is connected to the distribution grid are also calculated and analyzed. The research results are based on the connection standards of the distribution grid and use ETAP software for simulation. The results are analyzed, evaluated show that the applicability of this research in practice.

Keywords: *Solar energy, distributed energy resources, ETAP software.*

TÓM TẮT

Hiện nay, các nguồn năng lượng mới và tái tạo tích hợp vào lưới điện trung áp của Việt Nam đang phát triển mạnh trên phạm vi toàn quốc. Thực tế vận hành cho thấy, việc tích hợp các nguồn năng lượng tái tạo vào lưới điện phân phối đang gây nên những vấn đề về chất lượng điện năng như quá điện áp, gia tăng tổn thất công suất trên lưới và đặc biệt là ảnh hưởng tới sự làm việc của hệ thống rơ le bảo vệ. Bài báo này, phân tích đánh giá tác động của Nhà máy điện mặt trời Yên Định tại Thanh Hóa, Việt Nam khi kết nối vào lưới điện 22kV như: trào lưu công suất ngược, quá điện áp, ảnh hưởng sóng hài, thay đổi phương thức vận hành đặt tụ bù kinh tế và phối hợp bảo vệ khi nhà máy kết nối với lưới điện phân phối cũng được tính toán và phân tích. Các kết quả nghiên cứu dựa trên các tiêu chuẩn đấu nối của lưới điện phân phối và sử dụng phần mềm ETAP để mô phỏng. Các kết quả được phân tích, đánh giá cho thấy khả năng ứng dụng của nghiên cứu trong thực tế.

Từ khóa: *Năng lượng mặt trời, nguồn điện phân tán, phần mềm ETAP.*

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1. INTRODUCTION

Over the past decade, solar power has developed continuously, with both main types of technology, which are SPV (Solar Photovoltaic) photovoltaic technology and CSP (Concentrated Solar Power) solar energy technology. Recently, the solar power contribution to meeting human energy needs has become increasingly significant. With the current trend of using clean energy in the world, solar power production is an industry that is continuing to develop and improve continuously. As a sustainable and long-term energy source, solar power is a potential alternative to traditional energy sources. Solar power does not pollute the environment. The global solar power market in 2023 increased slightly compared to 2022 but solar power remained the fastest growing energy technology in the world, growing cumulative capacity is about 25%, bringing the total installed capacity of solar power (PV) to 505GW, annually producing nearly 640TWh of electricity equivalent to about 2.4% of total global electricity production (Fig. 1) [1].

Vietnam has great solar energy potential large, with technical potential of about 1677.5GW. Solar energy is largely concentrated in the south central, southeast and central highlands with numbers 300 days of sunshine/year, radiation intensity about 5kWh/m^2 per day [2]. The intensity of solar radiation in some territories in Vietnam is presented in Table 1, which is a good for development of solar power. Power Plan 8 sets the goal of strongly developing renewable energy sources for electricity production, reaching a rate of about 30.9 - 39.2% in 2030, an orientation to 2050, the rate of renewable energy create up to 67.5 - 71.5%. In particular, the scale of solar power in 2030 is 20,591MW and in 2050 is 189,000MW, producing 252 - 291 billion kWh of electricity per year [3].

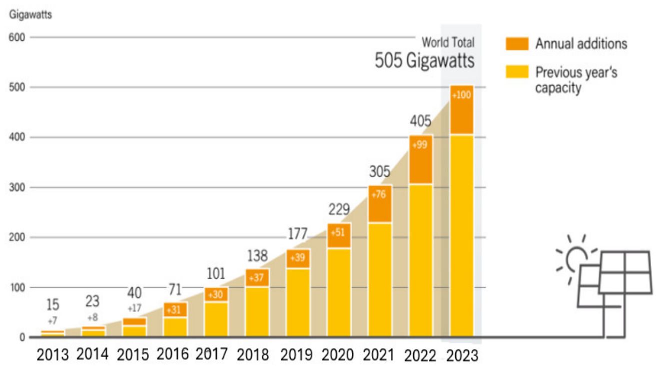


Fig. 1. Global new and cumulative PV installed capacity [1]

Table1. Data on solar radiation in territories in Vietnam [2]

No	Area	Solar radiation intensity (kWh/m^2.day)	Number of hours of sunshine per year
1.	Northeast	3.3 - 4.1	1600 - 1750
2.	northwest	4.1 - 4.9	1750 - 1800
3.	North Central	4.6 - 5.2	1700 - 2000
4.	South Central and CentralHighlands	4.9 - 5.7	2000 - 2600
5.	Southern	4.3 - 4.9	2200 - 2500
6.	National average	4.6	1700 - 2500

However, solar power generation capacity depends entirely on weather conditions, solar power capacity often fluctuates and sometimes changes suddenly (Fig. 2). On the blue line, there is a time when solar energy decreases by 35% within 5 minutes and 80% within 15 minutes [4]. Therefore, the regulated operation of the national power system is very difficult, with the risk of incidents and instability of the power grid. Coordinated relay protection also has difficulty in calculating the starting current of the relay and affects the sensitivity of the protection. According to a study [5], a solar power designed with a suitable capacity in the range of 4 - 6MW on a distribution line with a load of 10MW can minimize losses on the distribution line. When the solar power capacity exceeds the requirements of power loads, there will be a phenomenon of reverse power flow from the solar power location towards the intermediate station. This phenomenon will cause the following consequences: i) Increase losses and cause overload in the of the distribution line; ii) Overvoltage along distribution lines, affects the operation of distribution grid pressure regulators; iii) The protective relay operates incorrectly or does not operate when an incident occurs. iv) Phase imbalance and reduced intermediate transformer efficiency. Backward power transmission often results in the real power through the intermediate transformer being reduced much lower than the rated value. Besides, if solar power does not provide reactive power, or only provides a small part, the intermediate transformer still has to transmit a large amount of reactive power, leading to a large reactive power factor of the intermediate transformer low decrease. This increases intermediate transformer losses, and contributes to reduced distribution grid transmission efficiency [6].

This article analyzes and evaluates the impact of the Yen Dinh solar power plant in Thanh Hoa, Vietnam when connected to the 22kV power grid such as: reverse power flow, overvoltage, influence of harmonics, changes operational methods for placing economic capacitors and coordinating protection when the plant is connected to the distribution grid are also calculated and analyzed. The research results are based on the connection standards of the distribution grid and use ETAP software for simulation. The results are analyzed, evaluated show that the applicability of this research in practice.

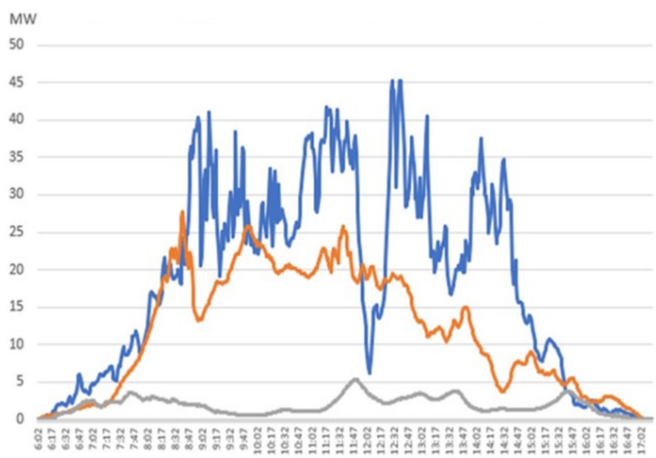


Fig. 2. Generating capacity chart of a solar power plant in Ninh Thuan, Vietnam [4]

2. CALCULATING THE POWER OUTPUT OF THE SOLAR POWER PLANT

Currently, determining the value of solar radiation intensity is calculated according to the formula or determined by automatic measuring devices and recorded by a data set in minutes, hours, days, months, years, using this type of data. Based on the results of calculating the intensity of solar radiation, can calculate the electricity output according to the total radiation value of the inclined surface according to the formula as follows [7]:

$$P = S.E_n.\eta \tag{1}$$

where: S is total receiver area (m^2); E_n is environmental radiation intensity by year ($kWh/m^2/year$); η is efficiency (%).

The intensity of solar radiation on the ground mainly depends on two factors: the angle of inclination of the light rays with respect to the surface plane at a given point and the path length of the light rays in the atmosphere or, in general, depends on altitude of the sun (angle between the direction from the observation point to the sun and the horizontal plane passing through that point). The relationship between atmospheric solar radiation and time of year can be determined by the following equation:

$$E_{ng} = E_0 \times \left(1 + 0.033\cos\frac{360m}{365}\right), W/m^2 \tag{2}$$

Where E_{ng} is the extra-atmospheric radiation measured on a plane perpendicular to the radiation ray on the nth day of the year. $E_0 = 6.25\times107W/m^2$ is the total radiation intensity of the sun.

The total radiation on the inclined surface will be the sum of the direct radiation E_b. B_b and scattering on the horizontal surface E_d (Fig. 3). Then an inclined surface making an angle ß with the horizontal will have a total radiation equal to the sum of 3 components:

$$E_{\beta\Sigma} = E_b.B_b + E_d\left(\frac{1+\cos\beta}{2}\right) + E_\Sigma R_g\left(\frac{1-\cos\beta}{2}\right) \tag{3}$$

where: $E_{\beta\Sigma}$ is the total radiation on the horizontal surface, R_g is the radiation reflectivity of the surrounding environment.

The radiation ratio B_b of the surface inclined at angle β compared to the horizontal surface:

$$B_b = \frac{E_n}{E_{bng}} = \frac{E_n.\cos\theta}{E_n.\cos\theta_z} = \frac{\cos\theta}{\cos\theta_z} \tag{4}$$

with: E_n is the intensity of incoming solar radiation in any direction, E_{bng} is solar radiation perpendicular to the horizontal surface, E_{bngh} is solar radiation perpendicular to the inclined plane.

cosθ and $\cos\theta_z$ are determined by the above equations and the angles shown in Fig. 3.

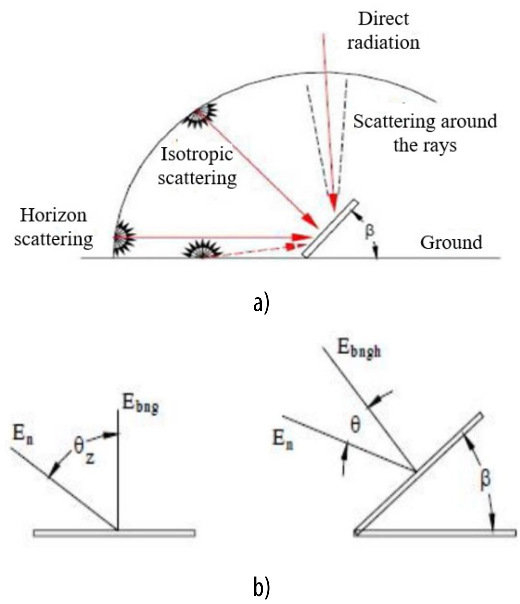


Fig. 3. Radiation components on inclined surfaces (a), Direct radiation on horizontal, inclined surfaces (b) [7]

3. SOLAR POWER PLANT INFORMATION AND IMPLEMENTATION STEPS

To model the solar power plant and distribution grid in reality, the research team used PVsyst software to simulate the real system installed in the area under study, determining the normalized power output with Actual climatic conditions of the areas for distribution grids. These results are used as input for the ETAP model to calculate power flow and voltage at busbar nodes of the grid, determine economic compensation capacity, and calculate harmonics. In addition, it also determines the three-phase and single-phase short circuit current, thereby determining the starting current of the relay protection in case there is no solar power plant and in case there is an operating solar power plant.

In this study, it is applied to Yen Dinh solar power plant in Yen Dinh district, Thanh Hoa province. This plant belongs to the type of ground-mounted solar power plant. Factory scale: Land area: 48.86ha, installed area 35.16ha, total installed capacity is 30.8MW, solar power plant layout shown in Fig. 4. The solar power plant includes 2 distribution lines 22kV, each the distribution line is connected by 7 transformer stations 22/0.6kV, each station consists of 4 rows of panels, each row has 16x8 sets of panels connected together, describing a feeder as shown in Fig. 5. Parameters of a solar panel: P_{max} = 345Wp, open circuit voltage V_{oc} = 46.08V, working voltage V_{mpp} = 38.8V, current at maximum power I_{mpp} = 9.07A, short-circuit current I_{sc} = 9.52A, panel efficiency η = 17.7% and can be combined in a 600V DC system.

Fig. 4. Plan of Yen Dinh solar power plant

The group has developed the implementation steps described in Fig. 6.

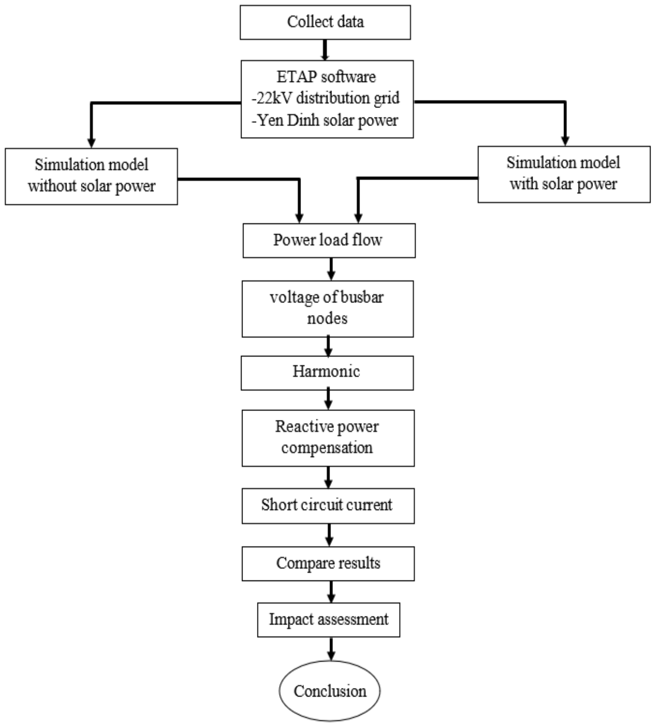


Fig. 6. Implementation steps

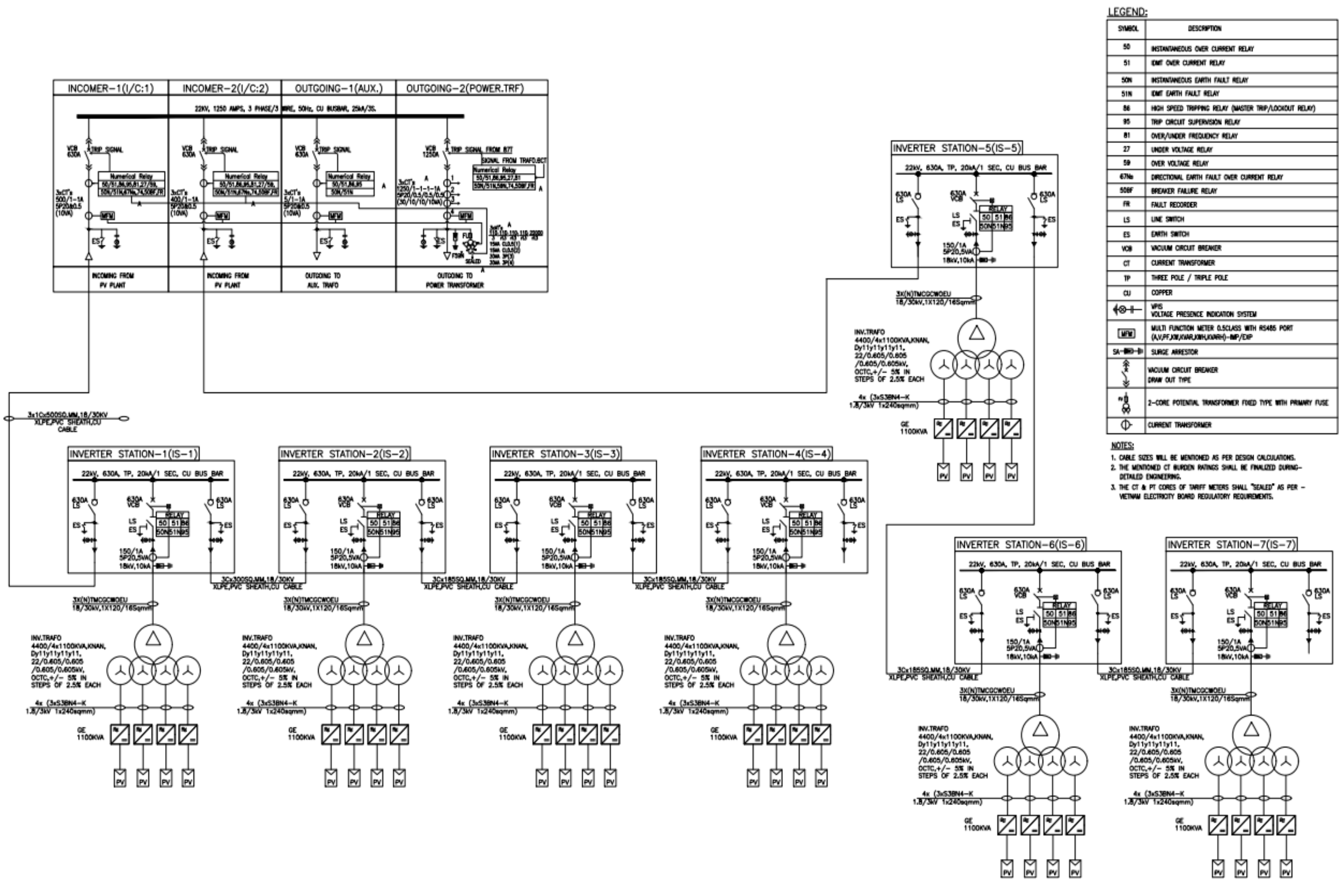


Fig. 5. Grid connection diagram of Yen Dinh solar power plant (Route 1)

4. RESULTS AND DISCUSSION

4.1. Impact of power reverse flow

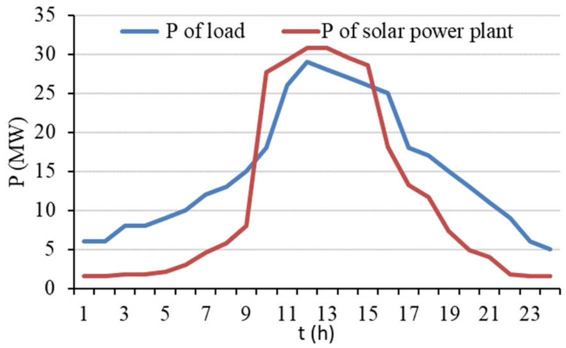


Fig. 7. Load capacity and generating capacity of solar power plant on a typical summer day

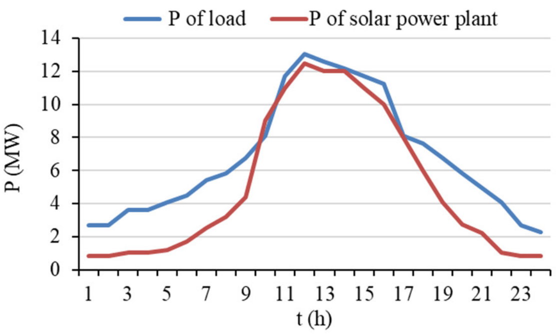


Fig. 8. Load capacity and generating capacity of solar power plant on a typical winter day

Using PVsys software, data on solar panels, connection configuration, solar radiation, and calculating the generating capacity of the solar power plant for a typical summer day and a typical winter day. Calculation results of the solar power plant's generating capacity and load capacity statistics are presented in Fig. 7 and Fig. 8. Total installed capacity is 30.8MW. On a typical summer day Fig. 8, with the current situation of solar radiation in the area, the generating capacity of Yen Dinh solar power plant during the summer peak period reaches a maximum of 18.8MW (60% of installed capacity) during the period from 12:00 to 13:00. During the period from 4:00 pm. to 9:00 pm., the Yen Dinh solar power plant's generating capacity is not enough to supply the load, so it must take capacity from the grid. The power flow on the 22kV distribution line flows from the grid to the factory. Meanwhile, from 9:00 am. to 4:00 pm, the generating capacity of Yen Dinh solar power plant has excess capacity for the load. The power flow on the 22kV distribution line flows in the opposite direction from the solar power plant to the grid. Thus, the 22kV distribution line has two power directions running through the day, the power direction from the grid to the solar power plant is the forward direction and the power direction from the solar power plant to the grid is called the reverse direction (power reverse flow). Changing power direction will affect the power transmitted through the transformer, leading to increased power loss.

4.2. Overvoltage impact

Calculations show that when with Yen Dinh solar power plant is put into operation, the problem of voltage drop at the end of the line is significantly improved compared to when there is without solar power plant in operation (Fig. 9). The results show that at positions 12, 18, 24 the voltage has improved significantly when the solar power plant is operating.

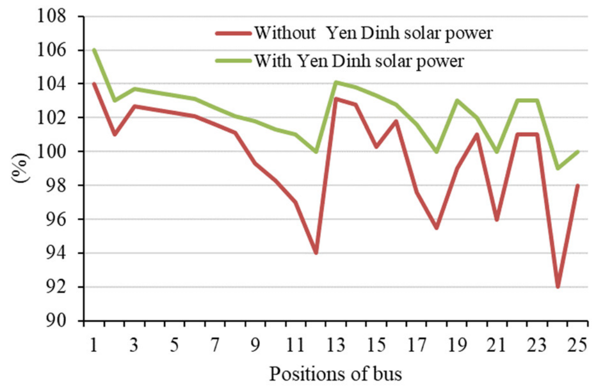
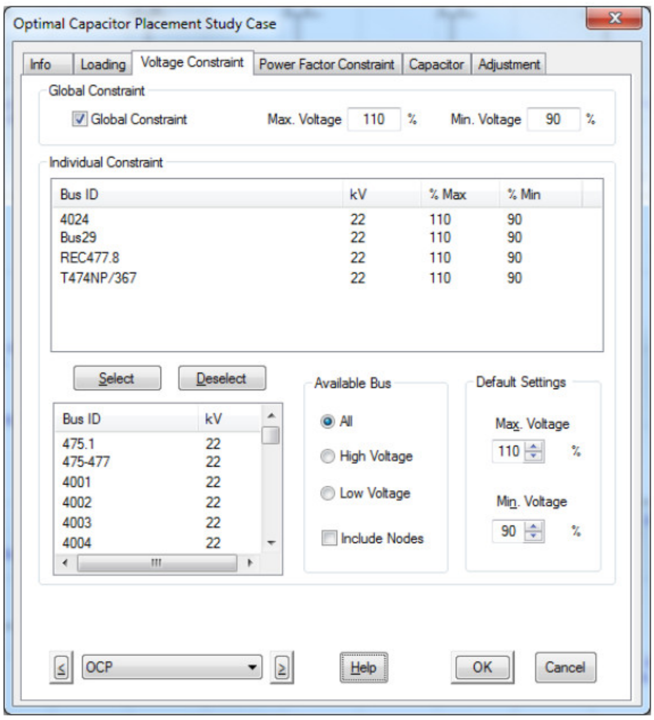


Fig. 9. Voltage at locations before and after the factory

4.3. Change the operating method of placing economic capacitors



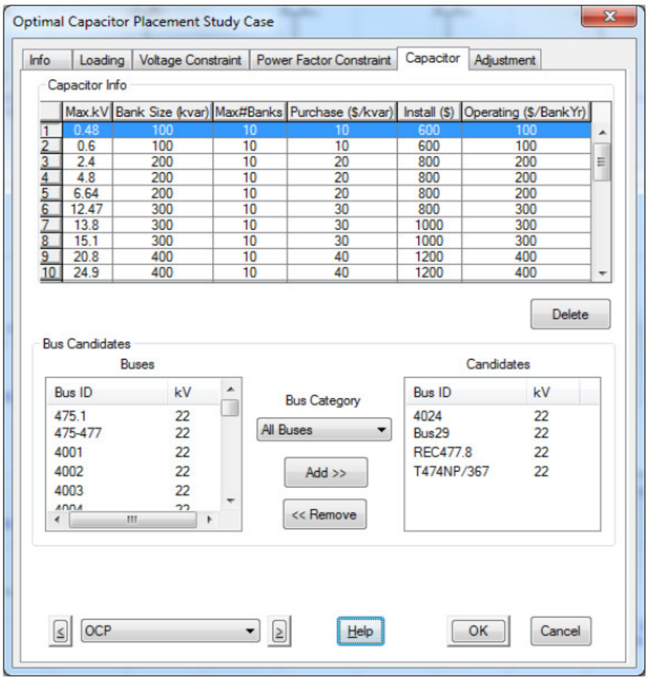


Fig. 10. Calculation of economic compensation for Yen Dinh solar power plant by ETAP

To demonstrate the influence of Yen Dinh Solar Power Plant on the selection of optimal capacitors, the research team implemented the problem of placing optimal capacitors at the end of the 22kV distribution line. The problem is to ensure voltage stability at the end of the line with assumed costs and input parameters for two scenarios: i) before Yen Dinh Solar Power Plant comes into operation, and ii) after Yen Dinh Solar Power Plant comes into operation. operate. The input parameters for the problem of evaluating the influence of Yen Dinh 1 solar power plant on optimal capacitor setting are as shown in Fig. 10.

Through analysis and comparison of the problem of optimal capacitor placement, the operation of Yen Dinh solar power plant changes the location as well as the optimal economic compensation capacity as shown in Table 2, contributing to significantly reducing costs. Installation, operation and maintenance of capacitor banks.

Table 2. Operating method for placing economic capacitors

	without Yen Dinh solar power plant	with Yen Dinh solar power plant
Optimal economic compensation capacity	4000 kVAr	1600 kVAr
Investment costs	100%	30%
Operating costs	100%	26%

4.4. Evaluate harmonic effects

In Yen Dinh solar power plant, inverter elements generate harmonics of the 5th order and higher, causing current and voltage distortion. To evaluate the THD impact of Yen Dinh solar power plant, the research team built a calculation scenario with assumptions and inputs for the harmonic sources of the Inverter units with waveform graphs and source spectra. harmonics as shown in Fig. 11. After running harmonic analysis, it was found that the total harmonic distortion at busbar 1 in the area near the harmonic source does not exceed the prescribed threshold of 6.5% THD (THD = 4.54%).

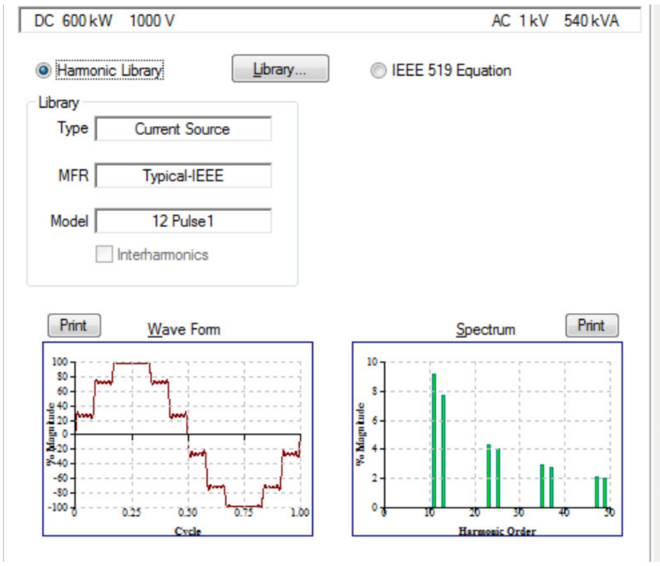


Fig. 11. Calculation of harmonics

4.5. Evaluate the impact on relay protection coordination

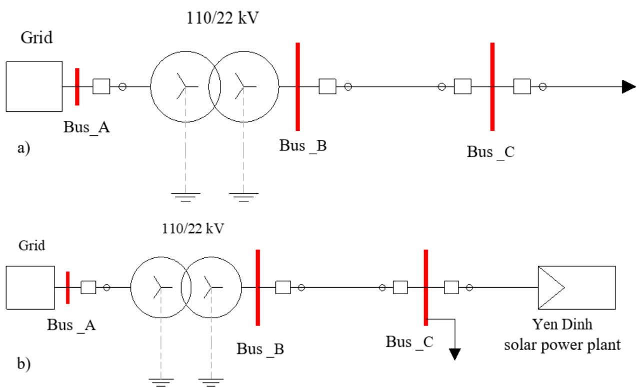


Fig. 12. Schematic diagram of distribution grid connection, without (a) and with (b) Yen Dinh solar power plant

Relay adjustment parameters at Yen Dinh solar power plant are carried out by the national power system dispatcher for each protected object. For the T1 40MVA transformer, the main protection is differential protection relay (87), fast trip protection (51) and timed overcurrent protection (50). For 22kV line using relay 50/51, the protection principle diagram is depicte in Fig. 12.

Within the scope of this article, we will evaluate the impact of Yen Dinh solar power plant on the protection of the 22kV line, using quick cut protection (51) and timed overcurrent protection (50). Fast cut protection starting current [8-11]:

$$I_{kd} = K_{at} . I_{Nngmax} \quad (5)$$

Timed overcurrent protection starting current:

$$I_{kd} = \frac{K_{at} . K_{mm}}{K_{tv}} . I_{LVmax} \quad (6)$$

Protection sensitivity

$$K_{nh} = \frac{I_{NMmin}}{I_{kd}} \quad (7)$$

With: I_{kd} is starting current of the protector; I_{Nngmax} is maximum external short circuit current, I_{LVmax} is maximum current, I_{Nmmin} is minimum short circuit current, K_{at} is safety factor, K_{mm} is starting factor, K_{tv} is return coefficient, K_{nh} is sensitivity.

Set up a diagram of the distribution grid connection principle of Yen Dinh solar power plant in ETAP software. Calculate power network analysis and calculate short circuit on the 22kV busbar in two cases when there is without Yen Dinh solar power plant and when there is with Yen Dinh solar power plant (Fig. 13). The results of calculating the maximum working current through protection 50 and the maximum short-circuit current at busbar C through protection 51 are presented in Table 3.

Table 3. Calculation results of working current and maximum short-circuit current

	without Yen Dinh solar power plant	with Yen Dinh solar power plant
I_{LVmax} (A)	946	552
I_{Nngmax} (kA)	15.467	11.83
I_{Nngmin} (kA)	13.238	10.139

From there, the starting current of protection 50, 51 is determined and the sensitivity is also calculated (K_{at} = 1.2; K_{mm} = 3.5; K_{tv} = 1) before Yen Dinh solar power plant operates and after the power plant operates. Yen Dinh solar power plant (assume the generation capacity is taken at the time it reaches 50% of the plant's installed capacity). The results show that, when the Yen Dinh solar power plant is not in operation, the starting current of protection 51 must be selected 1.3 times larger and that of protection 50 must be selected 1.7 times larger (Table 4).

Table 4. Calculation results of starting current and protection sensitivity before and after operation of Yen Dinh solar power plant

	without Yen Dinh solar power plant	with Yen Dinh solar power plant
I_{kd} of relay 51 (kA)	18.56	14.19
I_{kd} of relay 50 (kA)	3608	2107
K_{nh} of relay 51	3.6	4.8
K_{nh} of relay 50	0.71	0.71

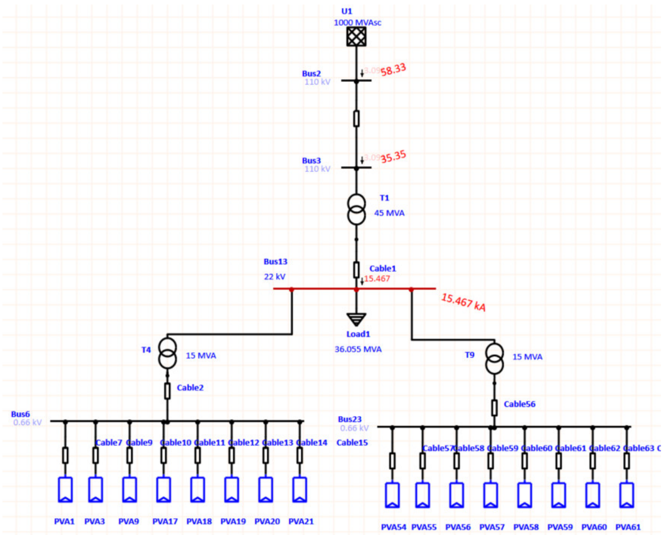


Fig. 13. Short circuit calculation in ETAP

Thus, it can be seen that when there was no Yen Dinh solar power plant, the starting current of the 22kV line, with protection 51 was 18.56kA and with protection 50 was 3608A. When the Yen Dinh solar power plant is in operation, the inrush current of the 22kV line protection with protection 51 is 14.19kA and with protection 50 is 2107A. In this case, the overcurrent relay placed at busbar A (bus_A) will not operate because the short-circuit current drops to the value 11.83kA, below the set threshold of 15.467kA. Due to the participation of the 22kV line impedance component connected from Yen Dinh solar power plant, the short-circuit current passing through the protection at bus_A and bus_B is reduced. Therefore, the protection at bus_A may not operate, or may operate with a delay longer than required when there is short circuit at bus_C. In this case, the relay at bus_A operates below threshold. In contrast, the short-circuit current flowing through the relay located at bus_B before the distributed power connection is 15.467kA. Thus, it can be seen that, when Yen Dinh solar power plant is connected to the distribution grid, the overcurrent protections in front of the connection point will operate below the threshold, leading to the entire protection system located on the main shaft segment to lose selectivity.

5. CONCLUSION

The article focuses on evaluating the impact of Yen Dinh solar power plant on reverse power flow, overvoltage, economic capacitor placement operation method, harmonic influence and protection system on the electrolysis grid 22kV distribution. Research results have shown that, when Yen Dinh solar power plant connected to grid, the operating method of the system changes because the generating capacity of Yen Dinh solar power plant changes hourly or according to weather conditions. The voltage at nodes on the 22kV grid has been significantly improved. Besides, both the direction and value of the short-circuit current distributed on the grid can be changed. This will directly affect the protective relay system that has been installed according to the power grid configuration when there is no connection to Yen Dinh solar power plant. The protective relay system can non-selectively or over-threshold impact on protections at the end of the distribution line and under-threshold impact on protections at the beginning of the distribution line. Further research will develop towards building adaptive protection features and ensuring selectivity when connected to distributed power sources.

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THÔNG TIN TÁC GIẢ

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