

Research and Analysis on Rainwater Harvesting and Utilization Technology of Unattended Substation

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Abstract: The rainwater collection and utilization technology in substation was investigated, and then a novel water-saving technology system for green substations is presented in this paper. A 220kV substation was chosen as the example to analyze the system. The results showed that it can save 278.5m³ water resource. It can provide important reference for rainwater collection and utilization in unattended substation.

1 Introduction

With the continuous development of China's economic construction and the improvement of people's living standards, China's electric power industry has entered a super period characterized by great rapid development. It witnessed a great quantity increase in substations which have been distributed everywhere in China. Therefore, there are urgent demand for energy saving, environmental protection and sustainable development. It is an indispensable part of the substation's design that how to optimize water supply and reduce the environmental pollution and damage caused by rainwater and sewage discharge. Therefore, unattended substation rainwater collection and utilization technology are critical to the design of green substation.

In the research on rainwater collection and utilization of substation, Nianyong Yang 1 conducted a feasibility analysis on the application of rainwater collection and the utilization in substation, and introduced the composition and main equipment of rainwater collection and utilization. Zhonglun Lei 2 conducted an analysis on the comprehensive utilization of rainwater, and analyzed the main features of the rainwater collection and utilization system. In addition, it was proposed that the rainwater collection of the substation should consider the overall collection. The research on integrated rainwater utilization technology was carried out by Mingpeng Gao³ on an arid area substation. Hong Xu⁴ conducted a preliminary analysis and researched on the realization mode of rainwater resources utilization from the aspects of rainwater collection, sewage interception and disposal, purification treatment, etc. It also gives a brief economy analysis of rainwater resources utilization in substations. This paper mainly presents the analysis of the rainwater collection and utilization of unattended substation, and the analysis of the principles of design, construction and economy. The results show that the rainwater collection and utilization system of substation has a great

significance on reducing the impact of rainwater drainage on the surrounding environment, thus it is able to improve the application of non-traditional water sources in substations, and reduce the exploitation of groundwater resources.

2 Structure and principle of rainwater collection and utilization system in substation

The rainwater collection and utilization facilities are composed of water catchment, collection system, storm water disposal, rainwater storage, storm water treatment, clear water supply system and storm water use system. The whole process consists of five steps: rainwater harvesting, initial sewage interception and split-flow, treatment and purification of rainwater, storage of rainwater, use of rainwater. Rainwater utilization can be used for greening, road washing, flushing, fire fighting, etc.

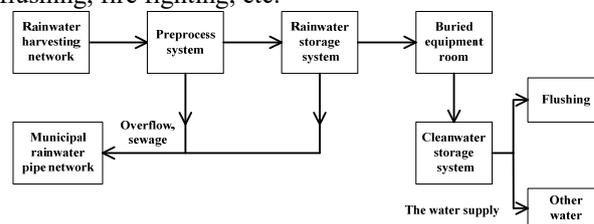


Figure 1. Structure diagram of substation collecting and utilization system

2.1 Rainwater collection

Rainwater collection in substations mainly includes roof rainwater, pavement and other hardened surface rainwater. Roof rainwater is generally of better water quality and can be collected directly from existing facilities such as rainwater hopper and storm water risers. Roof rainwater is the best choice of rainwater collection.

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There are a few roads and small areas in the substation; however, they are different from urban roads because of less rainwater pollution. Thus, rainwater from these places can be considered to be collected if conditions permit. Generally, the rainwater of pavement is collected through rainwater inlet and buried rainwater pipe, and the overflow outlet is also added when the original rainwater drainage pipe network system is to be reconstructed.

2.2 Sewage interception and split-flow of rainwater

The interception sewage basket is made of PE finished material, with built-in stainless steel filter mesh and non-woven cloth basket. The built-in filter mesh with the mesh size 2mm can block large rubbish and leaves. Split-flow filtering apparatus is briefly introduced as follows: the float ball can be moved up and down by the amount of rainwater flow, which can be used to switch device to realize the functions of initial rainwater split-flow, filtration, and automatic sewage and so on. According to the relevant research data, the initial rainwater runoff pollution was serious, and the content of COD, SS and chroma was high. In order to simplify the follow-up process, the facilities for sewage interception and split-flow. The split-flow facilities include volume type facilities, rainfall type facilities and flow type facilities. Volume type facilities are normally set at the front end of the reservoir and the end of the building rainwater pipe. The rainfall type facilities and flow type facilities are arranged on the rainwater pipe. Generally speaking, the runoff thickness of from 2 to 3 mm is used for roof split-flow and that of 3 to 5 mm is used for ground split-flow.

2.3 Treatment and purification of rainwater

The arts and crafts of rainwater purification treatment should be determined according to the collection method, the purpose of rainwater harvesting, the requirements of water quality standards for utilization, the collection area and rainwater flow, construction plan and related conditions, economic capacity and operation management maintenance conditions.

At present, the common processes can be summarized as follows:

- 1) Precipitation-filtration;
- 2) Coagulation-filtration;
- 3) Precipitation-reuse;
- 4) Coagulation-precipitation-filtration-disinfection;
- 5) Microflocculation-filtration-disinfection.

Rainwater reuse of unattended substations should include greening, road flushing, flushing, fire fighting, etc. Therefore, the 4th and 5th technological processes can be adopted. Chlorine tablets can be used as the disinfectant, which is simple and convenient.

2.4 Storage of rainwater

The rainwater, from roof or pavements or other hardened surfaces will be collected through rain funnels, pipes, etc. At the end of the rainwater pipe network, the rainwater is

filtered and then stored through simple pre-treatment system, and the exceeding designed treatment flow of rainwater is pumped to municipal rainwater networks. The rainwater storage system not only functions as rainwater collector, but also plays a role in adjusting and depositing the water resource.

3 The scheme design of rainwater collection and utilization system of substation

Based on the analysis of the technology of rainwater collection and reuse of a 220kV unattended substation in Hebei Province, a plan for rainwater collection and utilization was developed, which takes into account economy, practicability, stability and environmental effect, and so on. The conventional rainwater collecting system was replaced by roadway stone collecting ditch; Instead of the traditional rain water pump pool, PP module reservoir was used to store rainwater and recycled water. This paper adopts an integrated machine of rainwater physical-chemical treatment which is composed of coagulation, sedimentation, filtration and disinfection. The collected rainwater is regenerated, and the recycled water is stored in the pp water purification module for reserve stock. The specific scheme is shown in Figure 2

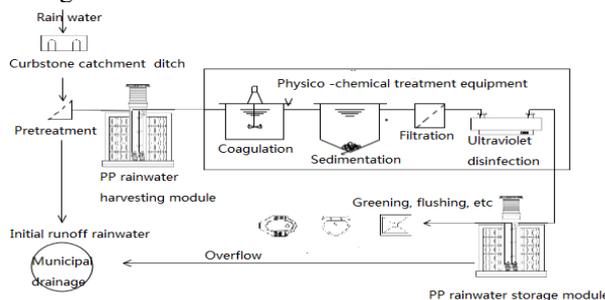


Figure 2. Scheme of rainwater collection and utilization system

3.1 Design and calculation of water requirement for unattended substation

The water consumption of the 220kV unattended substation includes domestic water and sprinkler suppository. The standard of water used for watering the road surface is 0.2~0.5L/m². The area of the sprinkler road is 1636 m². The amount of water used for watering the road is calculated as follows:

$$Q = \frac{q \cdot Fn}{1000} \quad (1)$$

In the formula, Q is the amount of water used for watering roads, m³ / d ;

q : The standard of water consumption for watering roads, L / m² · time ;

F : The area of the sprinkler road, m² ;

n : Number of times to sprinkle roads every day, time / d , once daily in the substation.

According to the formula, the daily water consumption for watering roads is $0.818 m^3$.

The domestic water quota of industrial enterprise buildings is 30~50L/ (person·ban), and the water time is 8 hours, and about 15 persons per shift is needed for the maintenance of unattended substation. The maximum daily water consumption is calculated as 0.75 and the maximum daily water requirement is 1.568 in the substation.

The 10%~15% of the maximum daily water consumption can be calculated as the sum of the leakage and unforeseen water in the pipeline network. Therefore, the maximum daily water requirement of 220kV unattended substation is $1.9 m^3 / d$. After the investigation, the maintenance of substation is mainly concentrated in March to May and September to November, with an average of 15 days per month. In summer and winter, the maintenance time of 220kV station is 9 days per month, thus the annual water demand of the station is about $292.5 m^3$.

3.2 Design and calculation of rainwater utilization flow of unattended substation

1) Preliminary estimation of rainwater runoff

The total amount of runoff from rainwater use and control can be simplified according to the Formula (2):

$$W = 10\Psi_c h_y F \quad (2)$$

W : The total runoff of rainwater design, m^3 ;

Ψ_c : The coefficient of rainfall runoff;

h_y : The thickness of design rainfall, mm ;

F : Catchment area, hm^2 ;

The design precipitation recurrence period: rainwater collection and utilization system should be 1-2 years.

Design rainfall thickness: precipitation thickness is calculated in days. The reference data of rainfall thickness should be based on the local rainfall statistics for the recent 10 years or more.

Catchment area: the catchment's area is the area of all hardened surfaces including roofing, pavement, plaza, parking, etc. The catchment area is calculated according to the horizontal projection area of the confluence surface.

2) Rainwater utilization of substation

Before the completion of the substation, the area is generally natural soil, vegetation or farmland. The rainfall is easily absorbed by plants or infiltrated into the soil to form groundwater. The runoff coefficient and runoff of the rainfall are relatively small. After completion, the impermeable area of buildings, structures and hardened roads will increase, and the permeable area will decrease accordingly. At this time, both the runoff coefficient and the rainfall runoff will increase. The rainfall runoff value at this time is called the maximum potential value of the rainwater utilization of this substation. Its calculation formula is:

$$W_p = 0.001\alpha_1 HF \quad (3)$$

In the formula, W_p is the maximum potential value of rainwater utilization, m^3 ;

0.001: Unit conversion factor;

α_1 : Under the condition of average rainfall for many years, the rainfall and runoff coefficient of the substation after the completion of the substation in the absence of rainwater utilization measures;

H : Average annual rainfall in the study area, mm ;

F : The area of the study area, m^2 .

After the substation is built, the increase in rainfall runoff after the completion of the occupied area should be used as much as possible. The rainfall runoff was restored to the value before the completion of the substation as far as possible to ensure the health of the ecological environment around the substation, and reduce the impact on the surrounding natural environment. The increased rainfall runoff after the completion of the substation is the reference value for the rainwater utilization of the substation. The calculation formula for the reference value of rainwater utilization of the substation is:

$$W_r = 0.001(\alpha_1 - \alpha_0)HF \quad (4)$$

In the formula, W_r is the reference value of rainwater utilization, m^3 ;

α_0 : Under the condition of average rainfall for many years, the rainfall runoff coefficient before the completion of the substation area;

3) Discharge quantity of initial runoff rainwater

The discharge quantity of initial runoff rainwater shall be determined according to the concentration of pollutants such as COD_{Cr} , SS and chromaticity collected from the underlying surface. The roof discarding flow can adopt 2~3mm runoff thickness, and the ground discarding flow can adopt 3~5mm runoff thickness.

The discharge quantity of initial runoff rainwater is calculated as follows:

$$W_i = 10 \times \delta \times F \quad (5)$$

W_i : The discharge quantity of initial runoff rainwater, m^3 ;

δ : Initial runoff thickness, mm ;

F : Catchment area, hm^2 ;

The average annual rainfall in this area is 518mm, and a 220kV unattended substation covers an area of about $8772 m^2$. The utilization of rainwater resource is shown in Table1.

Table1 Analysis of rainwater resources utilization in substation

	Regional runoff coefficient	Area/ m^2	Maximum potential value of rainwater utilization / m^2	Reference value of rainwater utilization / m^2 (after initial rainwater discarding)
Building roof	0.9	1200	559.44	447.55

Pavement and other hardened surfaces	0.85	1636	720.33	540.25
Macadam floor	0.4	5936	1229.94	368.98
Total		8772	2509.71	1356.78

In order to ensure that the ecological balance will not be destroyed and the normal surface seepage recharge after the substation is built, the amount of rainfall resources that can be utilized in the substation shall be the reference value for rainwater utilization. As can be seen from the table, the amount of rainwater that can be used in substations comes from roof runoff and the runoff from hardened surfaces, such as roads and operation path. The reference value of rainwater utilization in substation accounts for 54.06% of the maximum potential value of rainwater utilization, while the actual annual water consumption in substation takes up 19.36% of the reference value of rainwater utilization.

3.3 Design calculation of curbstone catchment ditch

1) Calculation of catchment cross-sectional A_2 :

$$A_2 = \frac{Q}{C\sqrt{Ri}} \quad (6)$$

In the formula A_2 : Cross-sectional area of catchment ditch, m^2 ;

Q : Maximum runoff of designed slope, m^3 / s ;

C : Chezy coefficient;

R : Hydraulic radius, m ;

i : Gullies ratio;

2) Calculation of Q :

$$Q = \frac{F}{6(I_T - I_P)} \quad (7)$$

In the formula, Q is the design maximum flow, m^3 / s ;

I_T : Maximum rainfall intensity at designed frequency 10min, mm / min ;

I_P : Average infiltration intensity of soil in corresponding time period, mm / min ;

F : Catchment area of slope surface, hm^2 .

3) Calculation of R :

$$R = \frac{A_2}{x} \quad (8)$$

In the formula R : Hydraulic radius, m ;

A_2 : Cross-sectional area of catchment ditch, m^2 ;

x : Wetted perimeter of catchment cross-sectional, m .

Table 2 Specification and dimension of curbstone catchment's ditch

Model	Inner width	Outer width	otal height	Lengt h

YT-LYD500	100mm	150mm	320/500mm	500m m
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According to the formula, combined with the model size (see Table 2), the dimension of curbstone catchment ditch is suitable for the size of 100mm (inner width) × 500mm (total height) × 500mm (length).

3.4 Design of rainwater treatment process

According to the water quality characteristics of rainwater in a 220kV unattended substation, physical and chemical treatment is adopted. It can be operated easily and has low maintenance cost.

The physical and chemical treatment method is conducted by full automatic cleaning filters and ultraviolet sterilizers. A filter of the automatic cleaning filter is used to directly intercept impurities in the water, remove suspended solids and particulate matter in the water, reduce turbidity, purify water quality, reduce the production of systemic fouling algae and rust, so as to purify the water and protect the precision equipment of other equipment in the system. By using a specially designed long-life C-band ultraviolet light generating device with high-efficiency and high-intensity, the ultraviolet sterilizer will generate intense ultraviolet C light to illuminate the water. When various bacteria, viruses, parasites, algae and other pathogens in the water are exposed to a certain amount of ultraviolet C light, the DNA structures of their cells will be destroyed, and they will be killed without using any chemical drugs. Thus the purpose of disinfection and purification is achieved.

The amount of treated water of the rainwater purification treatment device is determined according to the following formula:

$$Q_y = \frac{W_y}{T} \quad (9)$$

Q_y : The amount of water of facility handling, m^3 / h ;

W_y : The maximum amount of rain water used in the

rainwater supply system, m^3 ;

T : Daily operation time of rainwater treatment facility, h, it can take 24h.

According to the work schedule of the maintenance personnel of the substation, the operating personnel of the substation should be in the station for 8 hours during the maintenance of the substation, therefore the minimum capacity of the water treatment equipment should be $0.37 m^3 / h$.

After treatment, the water quality should meet the requirements of the Standard for Urban Miscellaneous Water Quality GBT 18920-2002, as detailed in Table 3.

Table 3 The standard for urban miscellaneous water quality

Project indicators	Gre eni	Road wateri	Toilet flushi
pH	6.0~9.0		
Colour/degree≤	30		
sniff	All pleasure		

Turbidity /NTU≤	10	10	5
Total dissolved solids / (mg/	100	1500	1500
Five-day BOD,BOD5 (mg/	20	15	10
Ammonia nitrogen / (mg/L)	20	10	10
Anionic surfactant / (mg/L)	1.0	1.0	1.0
Iron / (mg/L) ≤	--	--	0.3
Manganese / (mg/L) ≤	--	--	0.1
DO(DissolvedOxygen) / (mg/	1.0		
Total residual chlorine (mg/ L)	After 30 minutes of contact≥1.0, End of the pipe network≥0.2		
Total coliform bacteria / (per son/L) ≤	3		
COD _{Cr} (mg/L) ≤	30	30	30
SS (mg/L) ≤	10	10	10

3.5 Design of rainwater pp storage module

The rainwater pp module is a cubic structure composed of six panels. The pp module layout of the water storage should adopt I-type, F-type and E-type, with the maximum height of 4.5m and the soil cover height of 0.5~1.5m. It has the characteristics of large water storage capacity, convenient installation, good bearing pressure, long service life, moderate price and recyclability.

The rainwater tank adopts a pp module combination pool. The size of a single module is 1000mm*1000*425(h), and the load-bearing value is greater than 40 tons/cubic. The outer side of the PP module combination pool is covered with the waterproof package, and the inside can accommodate rainwater. The waterproof package is a two-cloth one-film structure, which means there is a PE film in the middle layer, and the outside is geotextile. The layers are connected in the form of common board, and the connection cards are connected between the columns. Such PP reservoir blocks are recyclable, and they can be dismantled and migrated to other areas. They can be used to create maintenance-free water storage tanks, and to collect rainwater continuously throughout the year, thus providing a large amount of water for garden irrigation. With simple construction and installation and no need for heavy lifting and transportation equipment, they can greatly reduce the construction period and improve efficiency. They have strong hardness and strength, and can be safely used with no odor in water, any precipitates, strong acid resistance and strong alkalinity.

The water used in a 220kV unattended substation includes a shitter, a urinal, a mop basin, a sprinkler, etc. The maximum daily water requirement of the station is 1.9m³/d. The maintenance of the substation mainly focuses on the spring and autumn, and the average monthly water consumption is 30 m³. The volume of pp water storage module should not be less than 31 m³, taking 3.5x3.5x3m as 36.75 m³.

4 Effect analysis

4.1 Water-saving benefit analysis

The monthly rainfall of the area where the substation is located distributed unevenly in the whole year, and the rainfall is concentrated between June and August. The rainfall distribution is shown in Figure 3.

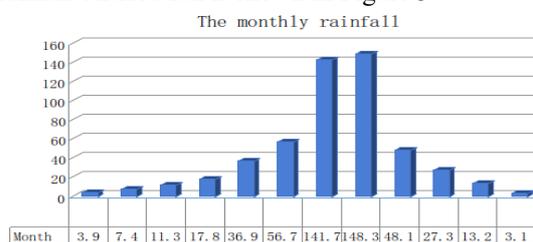


Figure 3. Average monthly rainfall distribution

The reference value of monthly rainwater utilization is calculated with the reference value of annual rainwater utilization. The calculation results are shown in table 4

Table 4 Reference value of rainwater utilization and water demand in station

	Water demand (m ³)	Reference value of rainwater utilization (m ³)
January	19	10.2
February	17.2	19.4
March	28.3	29.6
April	29.8	46.6
May	31	96.6
June	21.8	148.5
July	20.2	371.1
August	18.8	388.4
September	28	125.9
October	30.4	71.5
November	29.5	34.6
December	18.5	13.3

As shown in the table, the monthly water demand cannot be met by the quantity of monthly rainwater utilization in January and December. The quantity of water-saving in January and December is 10.2 m³ and 13.3 m³ respectively, and the quantity of annual water-saving is 278.5 m³.

4.2 Economic benefit analysis

According to the reference values of water demand and rainwater consumption of the substation in Table 4, we can draw a conclusion that the substation needs to transport water from outside in January and December, since the quantity of reused rainwater cannot meet the demand of water need in substation. All the drinking water in the substation that should meet standards of drinking water needs to be shipped from outside, and monthly demand for drinking water is 1.2 m³. So the total amount of water transported from outside is 28.4 m³.

The whole life cycle of outdoor substations is calculated according to 50 years in the analysis. Compared with the full life cycle cost of traditional deep well program, the collected rainwater for utilization + water transported from outside program analyzed by economic analysis is more economical.

Table 5 The cost comparison programme of the traditional deep well and the "rainwater harvesting and utilization + external transportation of water"

analysis in substation. Engineering Journal of Wuhan University , **44**, 69-72,85 (2011)

Serial number	Equipment	Investment (10,000 yua)	Remarks
The program of deep well			
1	300m deep well	102	
2	Maintenance costs	10	Repair every five years
Total		112	
The programme of rainwater harvesting and utilization + external transportation of water			
1	PP rainwater harvesting mod	8	
2	Physico-chemical treatment equipment	30	Physico-chemical treatment equipment is updated every 1
3	Underground concrete pool	2	
4	PP rainwater storage modul	5	
5	Total cost of water shipment	10.58	
Total		36.58	
economy		56.42	

5 Conclusion

Within the unattended substation, there is less demand for water. And policy and economy highly influence traditional deep well program, so an alternative program is urgently needed. For the collect rainwater for reuse program, additional stormwater treatment and storage facilities can effectively collect and utilize rainwater. Therefore, the goals of saving water resources and reducing sewage discharge are realized. The application of rainwater utilization in substations has extensive social, environmental and economic benefits. It is an important guarantee for sustainable development, and it also is one of the development directions that build "green" substation.

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