

# In-Depth Study on Synthesis Load Modeling

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Received April, 2013

## ABSTRACT

Detailed procedures for the modeling of synthesis load models (SLM) of actual power network are presented, then the classification indices based on load characteristics and the principle of load classification are expounded. Based on the results of general investigation of 220 kV and 330 kV substations in China's power grid, the load characteristics are classified, and detailed load characteristic investigation of selected different kinds of typical substations are carried out. By use of statistical synthesis, the SLM for typical substations, in which the distribution networks are taken into account, are built; and the modeling results are disseminated and applied to whole Chinese power grid. Besides, the load model parameters are evaluated and verified via post-disturbance simulation method. The effectiveness of the built SLM is validated by the fitting of some disturbance incidents.

**Keywords:** Chinese Power Grid; Load Characteristics; Load Composition; Load Modeling; Synthesis Load Model (SLM)

## 1. Introduction

Load modeling is critical for power system dynamic analysis [1]. In power system stability analysis, inappropriate load models could introduce non-consistent even reversely against actual results [1-5]. The study results from CIGRE workgroup indicate that precise load models could help operation engineers to accurately estimate the system operation limits. In other words, the load models with large differences from actual case could introduce wrong analysis outcome, resulting in improper security and stability control measures, further worse operation and finally system splitting and blackout [6]. In 1987, the voltage collapse accident in Japan was mainly caused by heavy load. The voltage decreased after accident, and the reactive power characteristics of air-conditioning loads made the further decrease of voltage [7]. The results from WSCC load modeling workgroup in USA show that pure static load model over estimates the damping characteristics. Only the hybrid model with 25% motor model can achieve fairly accurate dynamic stability characteristics [8-9]. For transit power system angle stability analysis, the plant electric consumption has significant impact on stability characteristics of generators, since the percentage of plant electric consumption in most thermal power stations can reach 4%~6%[10]. Therefore load modeling becomes a hot topic in academic and power grid companies in China and overseas.

Chinese power grid covers very large areas with com-

plicated structure, including typical huge power supply sending-end systems, e.g. west Inner Mongolia power grid and Shanxi power grid, and typical large receiving-end power centers, e.g. Beijing-Tianjin-Tang-shan grid. There exist dynamic stability and receiving-end voltage issues of inter-connected power grids, due to long distance between sending-end and load center. Thus load characteristics have obvious impacts on the stability characteristics of Chinese power grid.

Now Chinese regional power grids usually use uniform load models and parameters in simulation, which are non-conformant with practical situations. One of the most effective methods is load survey, and load modeling based on practical composition of each substation. But there need huge work for load modeling for each substation. Thus some typical substations should be modeled with practical loads, then promote typical models in whole power grid.

## 2. Power Grid Load Survey and Classification

### 2.1. Load Characteristics Survey

The objective of load characteristics survey is to find the load type of each 220 (330) kV substation, then provide the base for further load classification and typical substation modeling. Load characteristics survey use table questionnaires, which are disseminated to province power grids. The survey covers wide range and need many people, e.g. dispatch and sales departments, involved in.

Considering the time variance of load, survey should focus on specified time range. This survey includes 2199 220 kV and 330 kV substations in China.

The content of survey includes the percentages of each load type in the substation. For example, the survey results of Chengxi substation are shown in **Table 1**.

Based on survey results, the substation load characteristics can be determined.

**2.2. Classification of Load Characteristics**

Based on survey results from above section, all the 220kV and 330kV substations are classified into several types, which could represent the load characteristics in this area. The classification principle and basis are shown in **Table 2**.

The survey scope in this paper includes 2199 substations in North China, Central China, East China, North-west China and Northeast China power grids. Based on the survey results, all 2199 220 kV and 330 kV substations are classified into ten types: (a) typical industry

load, (b) hybrid commerce & civilization load, (c) hybrid industry & civilization load, (d) hybrid civilization & agriculture load, (e) hybrid industry & agriculture load, (f) hybrid industry & civilization & agriculture load, (g) hybrid high energy consuming industry load, (h) electrolysis high energy consuming industry load, (i) direct-supply steel industry load, (j) marine chemical industry load. The statistical results are shown in **Table 3**.

**Table 1. Load composition statistical results for Chengxi substation.**

Load Type	Active Power (MW)	Reactive Power (MVar)	Percentage of Active Power	Percentage of Reactive Power
Industry	205	73	57%	62%
Commerce	46	11	13%	9%
Civilization	78	26	21%	22%
Agriculture	32	8	9%	7%
Total	361	118	100%	100%

**Table 2. Load classification principle of 220(330)kV substation.**

Load Type	Percentage of Industry Load (%)	Percentage of Commerce Load (%)	Percentage of Civilization Load (%)	Percentage of Agriculture Load (%)
Industry load	≥75	<20	<20	<20
Hybrid commerce & civilization load	<20	≥20	≥20	<20
agriculture load	<20	<20	<20	≥75
hybrid industry & civilization load	≥20	<20	≥20	<20
Hybrid industry & agriculture load	≥20	<20	<20	≥20
hybrid Civilization & agriculture load	<20	<20	≥20	≥20
hybrid industry & civilization & agriculture load	≥20	<20	≥20	≥20

**Table 3. Statistical results of load compositions.**

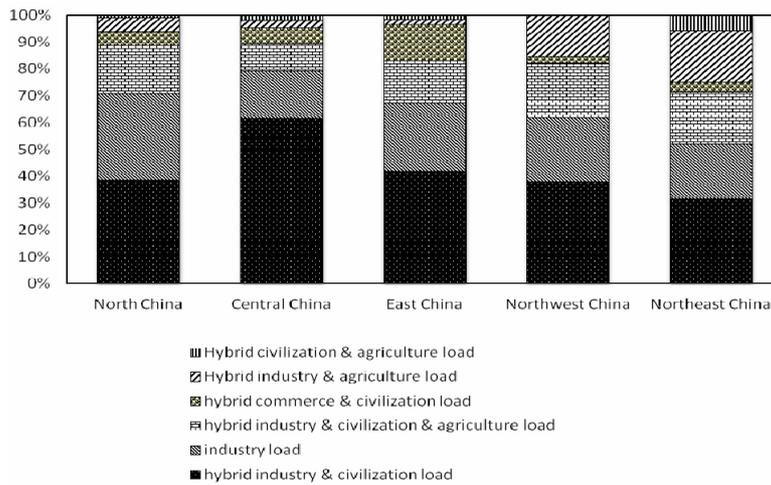
Load Type Index	North China	Central China	East China	North-east China	North-west China	Total
(a)	167	113	123	54	20	477
(b)	26	36	67	10	2	141
(c)	200	390	208	84	32	914
(d)	5	12	7	15	---	39
(e)	26	18	10	51	13	118
(f)	94	66	79	51	17	307
(g)	40	---	---	---	11	51
(h)	12	36	8	3	12	71
(i)	21	29	23	6	---	79
(j)	2	---	---	---	---	2
Total	593	700	525	274	107	2199

From the results of five Chinese regional power grids, the hybrid industry & civilization load substations are the biggest part, the second and third place are industry load and hybrid industry & civilization & agriculture load. The load characteristics distribution results are shown in **Figure 1**. **Figure 1** shows the distribution of several common load classes, since special load types, including steel industry, electrolysis and other high-energy-consuming industry, occupy small percentages in total power load of each regional power grid. It could be found that one common feature of all power grids: the biggest part is hybrid industry & civilization load and the second place is industry load. There are differences in other load classes of each regional power grid. For example, hybrid civilization & agriculture load is the third place (16%) in Northeast China power grid. While the same load class only occupies 2.7% in Central China power grid. The hybrid commerce & civilization load in North China power grid occupies 7.4% of whole load, since Bei-

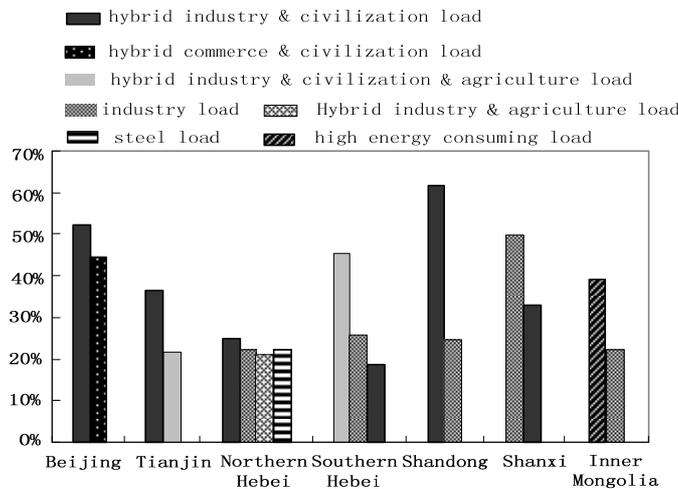
jing-Tianjin-Tanggu area is a large business load center, while there is nearly zero hybrid commerce & civilization load in Northwest China power grid.

Even in the same regional power grid, the load composition could be different between areas (province/city/autonomous region). **Figure 2** shows the main load distribution of seven areas grids in North China power grid.

It is found that besides hybrid industry & civilization load, 45% of whole load is commerce load and nearly zero industry load in Beijing, which is the political, economic and culture centre of China. Conversely in Shanxi power grid, industry load is the biggest part with 50%. In Southern Hebei power grid, 46% of whole load is hybrid industry & civilization & agriculture load, which is also significant part in Tianjin power grid. In West Inner Mongolia power grid, high-energy-consuming and industry loads are the main classes. It is clear that there are significant differences between load characteristics of different province/city in North China power grid.



**Figure 1. Column chart of the distribution of load types for the 5 regional power grids.**



**Figure 2. Column chart of the distribution of load types for North China power grid.**

From the comparisons of load characteristics between regional power grids, and different areas in the same regional power grid, it is found that the differences cannot be ignorable. It is necessary to divide substations into different classes, and model each load classes, to get SLM parameters applicable for practical power grids.

### 3. Selection of Typical Substation and Detail Survey

#### 3.1. Selection of Typical Substation

Usually the typical substations are selected according to load survey and classification results. From each load classes, typical substations with clear load characteristics and representative for its area will be selected.

240 typical 220 kV and 330 kV substations have been selected according to load characteristics survey, statistics and analysis, and considering both location and load composition. The selected substations have been investigated in details of distribution networks, load composition and load characteristics. The selected typical substations distribution is shown in **Table 4**.

The survey results show that hybrid industry & civilization load and industry load are the first and second place in load composition, and hybrid industry & civilization & agriculture load occupies significant part in most areas. Thus there are a large number of typical substations selected for these three load types, and the selection is adjusted in each regional power grid. It could be found from **Table 4** that the selected typical substations could represent the practical load composition in each regional power grid.

#### 3.2. Detail Survey of Typical Substations

There are large amount data in detail load characteristics survey of typical substation. The data include network topology of 220 (330) kV substations; transformer, line, reactive power compensation and relevant data of 220

**Table 4. Distribution of typical substations.**

Load Type Index	North China	Central China	East China	Northeast China	Northwest China	Total
(a)	24	16	18	6	2	66
(b)	3	4	7	1	1	16
(c)	14	23	14	8	3	62
(d)	1	1	1	1	---	4
(e)	6	3	1	6	1	17
(f)	14	9	10	6	1	40
(g)	7	---	---	---	1	8
(h)	2	6	2	1	1	12
(i)	4	5	4	1	---	14
(j)	1	---	---	---	---	1
Total	76	67	57	30	10	240

(330) kV substations; the load data of all feeders in survey time, including active power, reactive power, current, voltage, power factor, etc.; detailed load composition of each feeder.

The load types under survey include civilization load, commerce load, agriculture load, textile industry load, paper industry load, medicine industry load, food industry load, mechanic industry load, etc. Electrical power loads consist of many different electrical devices. To understand load composition, firstly should understand the main load types. Normally, power load could be divided into four types: 1) civilization load, including air-conditioning, lighting, electrical appliance, etc.; 2) commerce load, i.e. power consumed by business organization, e.g. business service organization; 3) industry load, including production, machining, manufacturing enterprises, e.g. mining, food, tobacco, textile, wood machining, furniture, paper, printing, chemical, oil chemical; 4) agriculture load, including farm irrigating, village etc.

Electrical demand consists of different load types, each load type consists of many electrical devices, which have different characteristics. Thus the percentage of each kind of electrical device is also important survey data.

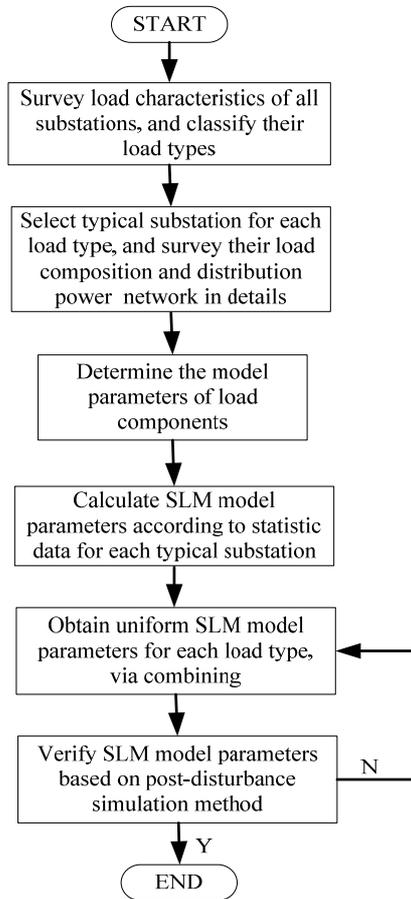
Chengxi substation is used as an example to show above method. The total load is about 361 MW in Cheng-xi substation. The detail load composition of Chengxi substation is shown in **Table 5**.

### 4. Load Modeling with Statistics Synthesis Method

The statistics synthesis method obtains the synthesized model of all loads connected with one node considering distribution networks, via a series of statistic and synthesis, i.e. the relationship of node active power and reactive power with node voltage and frequency variations. **Figure 3** shows the SLM modeling process based on statistic synthesis method and considering distribution network. The detailed survey results including substation load composition is the basis of SLM modeling, the kernel of load modeling is the calculation of SLM parameters according to statistic data.

**Table 5. Electrical device composition of Chengxi substation.**

Index	Load Type	Percentage (%)
1	Big industrial motor	46.31
2	Fluorescent Lamp	19.47
3	TV	9.59
4	Electrical furnace	8.4
5	Water heater	6.61
6	Cooling aircon	3.83
7	Refrigerating equipment	2.43
8	Washing machine	2.15
9	Small industrial motor	1.21



**Figure 3. SLM modeling process based on statistic synthesis method.**

The induction motor load is more than 60% of power loads. The power system load dynamic process within tens of seconds is mainly caused by induction motor. In previous research, the proposed motor cluster equivalence algorithms have issues in accuracy and applicability.

In this paper, the motor cluster equivalence algorithm in paper [12,13] is used. This equivalence algorithm divides the induction motor cluster into two sub-clusters, according to the rotor patterns and mechanic pattern resistance ratio. Then all motors could equivalent to single-machine equivalence model based on induction motor physical characteristics. In order to improve model accuracy, the master motor cluster is introduced to revise the model. Since the obtained single machine equivalence model has clear physical characteristics, the model performs good applicability even in large disturbance operation mode.

As shown in **Figure 3**, SLM modeling for typical substation is the basis of SLM model for whole power grid. Based on the practical load composition shown in **Table 3**, some representative substations have been selected as shown in **Table 4**.

For example, the Chengxi substation SLM model is shown in **Table 6**, in which ZP is the constant resistance component in static active power, ZQ is the constant resistance component in static reactive power, IP is the constant current component in static active power, IQ is the constant current component in static reactive power, PP is the constant power component in static active power, PQ is the constant power component in static reactive power, Nm is motor percentage, Lf is load factor, Tj is motor inertia time constant, Rs is motor stator resistance, Xs is motor stator reactance, Xm is motor excitation reactance, Rr is motor rotor resistance, Xr is motor rotor reactance, R\* is distribution network branch resistance, X\* is distribution network branch reactance.

After calculating SLM parameters for each typical substation, SLM parameters of the same load class in different regional power grids have been further synthesized. The SLM dynamic model, static model and distribution network equivalent impedance have been compared and combined, to calculate the uniform SLM parameters for this load type. The results show that SLM parameters of the same load type in different regional power grids have high similarity, which is the result of load characteristics classification principle introduced in Section 2.2. Based on such results, multiple typical substation SLM parameters could be combined into uniform SLM parameters for whole power grid.

In East China power grid, the hybrid industry & civilization load and industry load are the largest part of total load, with percentage of 40% and 23%. The SLM parameters for industry load and hybrid industry & civilization load in East China power grid have been listed in **Table 7** and **Table 8**.

**Table 6. SLM parameters for Chengxi substation.**

ZP%	ZQ%	IP%	IQ%	PP%	PQ%
34	34	43	43	23	23
Rs	Xs	Xm	Rr	Xr	Tj
0.015	0.118	3.67	0.01	0.118	2.82
Nm	Lf	R*	X*		
56%	0.4	0.004	0.08		

**Table 7. SLM parameters for industry load.**

ZP%	ZQ%	IP%	IQ%	PP%	PQ%
10	10	70	70	20	20
Rs	Xs	Xm	Rr	Xr	Tj
0.015	0.118	3.68	0.04	0.118	2.84
Nm	Lf	R*	X*		
70%	0.4	0.003	0.08		

**Table 8. SLM parameters for hybrid industry & civilization load.**

ZP%	ZQ%	IP%	IQ%	PP%	PQ%
34	34	43	43	23	23
$R_s$	$X_s$	$X_m$	$R_r$	$X_r$	$T_j$
0.015	0.118	3.67	0.04	0.118	2.82
$N_m$	$L_f$	$R^*$	$X^*$		
55%	0.4	0.004	0.08		

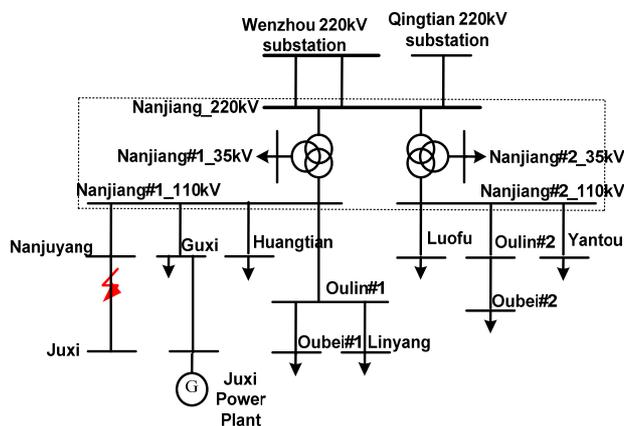
Compared with existing 40% constant resistance+60% constant power static model used in East China power grid, SLM considers load dynamic characteristics: the motor percentages in industry load and hybrid industry & civilization load are 70% and 55%, respectively. The static load composition of SLM is more complicated than that of existing static model. SLM motor inertia time constant of industry load is higher than that of hybrid industry & civilization load. The SLM motor exciting reactance of industry load is also higher than that of hybrid industry & civilization load. The key reason is that industrial motor has higher load inertia than residential motor, and industrial motor also has higher exciting reactance.

### 5. SLM Model Verification Based on Disturbance Incidents

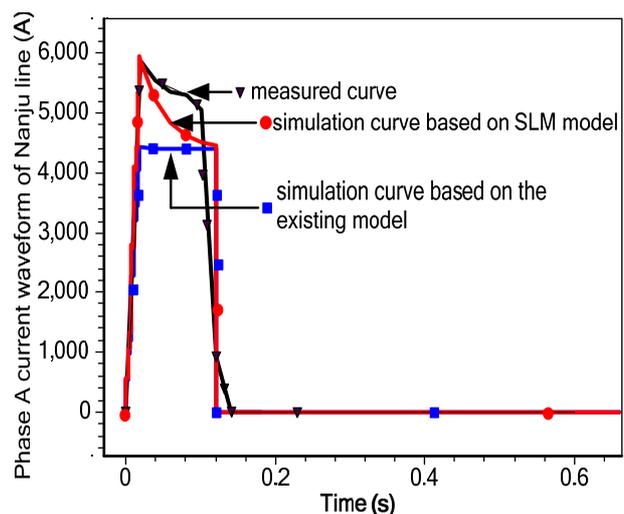
In this section, the post-disturbance simulation method is used to verify SLM parameters, by collecting various disturbance incidents in practical power grids.

In May.20, 2007, three phase short circuit fault happened at the Nanjiang side of 110 kV Nanju line. This incident is a typical incident close to load side. Following figure shows the electric connection chart of Nanjiang 220 kV substation.

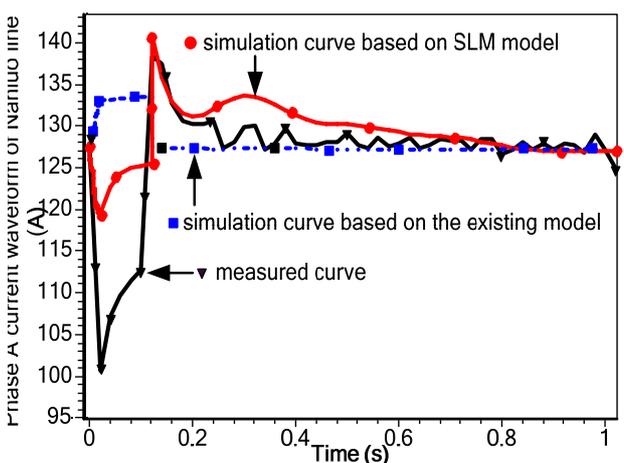
From **Figure 4**, it is clear that Nanju line had no load when the fault happened. The Nanju line and Nanluo line(Nanjiang bus #2 to Luofu) fault current simulated by both existing load model and SLM model, and measured current curves are shown in **Figure 5**. For fault line current, the existing model simulation result has greatest 1kA difference from measured one. While SLM simulation results are closer to measured results. For non-fault line current, the existing model simulation results change conversely with the measured curve during the fault duration. After the fault duration, the change features are also quite different from the measured curve. The simulation curve based on SLM model results change close to the measured curve with small variance. Based on above results, it is clear that SLM has higher simulation accuracy in current simulation.



**Figure 4. Electric connection chart of Nanjiang 220 kV substation.**

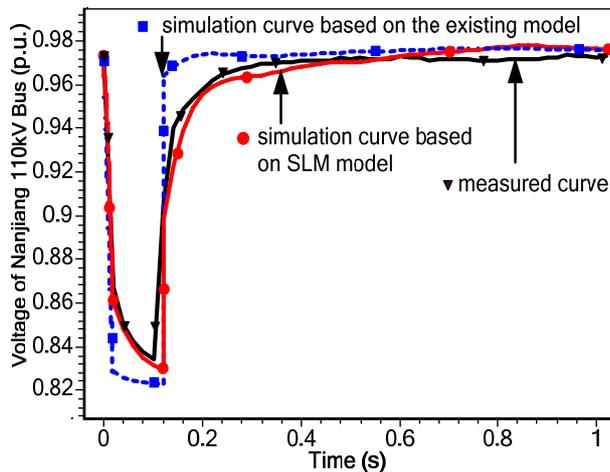


(a)



(b)

**Figure 5. Comparing the simulating fault current curves for different load models with the measured curve when a three-phase fault is occurred on the 110 kV transmission line from Nanjiang to Juxi. (a) 110 kV Nanju line fault current curves. (b) 110 kV Nanluo line fault current curves.**



**Figure 6. Comparison of voltage curves of Nanjiang 110 kV bus for different load models.**

Nanjiang bus #2 voltage curves simulated by both existing load model, SLM, and measured voltage curve are shown in **Figure 6**.

From **Figure 6**, in existing model simulation results, the bus voltage recover very fast to original level with even no delay, while the measured voltage recovers slower. SLM simulation results are close to measured ones with small variance. Thus it is clear that SLM model has higher accuracy in voltage simulation.

## 6. Conclusions

Detailed procedures for the modeling of synthesis load of actual power network have been proposed in this paper, then the classification indices based on load characteristics and the principle of load classification have been expounded. The load characteristics of 2199 220 kV and 330kV substations in Chinese five regional power grids have been surveyed. Based on the results of general investigation, the load characteristics have been classified according to the proposed principle, then based on the detailed investigation and statistics of load composition at 220 kV and 330 kV substations, the distribution of different types of load in domestic power grids has been analyzed and 120 typical substations have been selected. Detailed load characteristic investigation of these selected different kinds of typical substations has been carried out. The statistical synthesis method has been used to model typical substations with SLM model parameters. The SLM model parameters of same load types in different regional power grids have been synthesized, and the dynamic model, static model and distribution power network equivalent reactance have been compared and combined, then unified SLM model parameters in whole power grid have been introduced. Finally, the load model parameters have been evaluated and verified via post-

disturbance simulation method. The effectiveness of SLM has been validated by the fitting of some disturbance incidents.

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