Energy Management System Architecture for New Energy Power Supply System of Islands

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***Abstract*—New energy power supply system (NEPSS) is a promising development trend of small and medium-sized island power system. NEPSS has three major characteristics. First, there is a high proportion of new energy generation (NEG) in the NEPSS. Second, NEPSS is exposed to more natural disasters. Third, autonomous operation is widely adopted in the NEPSS. In this paper, energy management system architecture is designed for NEPSS. In the architecture, there are seven modules: bad data identification and repair module, state estimation and pattern recognition module, load and NEG forecasting module, security early warning and protecting module, dispatch plan module, disaster assessment and disposal module, and black-start decision support module. The NEPSS dispatch plan is specifically discussed in term of different horizons and operation modes. Finally, a rolling method for adjustments of dispatch plans is proposed.**

***Index Terms*--Energy management system, power generation dispatch, renewable energy sources.**

I. Introduction

ENERGY management system (EMS) , the central nerve system of power system, is an advanced operation decision-making system which is developed on the basis of real-time monitoring and state estimation, and has been developed and used widely in transmission network and distribution network with the progress of technologies (e.g., computer technology) since the 1970s [1], Driven by smart grid technology, bulk power system (BPS) EMS is being developed more and more intelligent [2].

Microgrid is a novel power supply system. It is firstly proposed by American Consortium for Electric Reliability Technology Solutions. New energy (e.g., wind energy and photovoltaic energy) can be used effectively in the Microgrid [3]-[7]. Microgrid EMS (there is a similar concept of microgrid control center [8]) is the core component of the microgrid. So far, relevant research on microgrid EMS has been carried out mainly in three aspects: functions and advanced applications, information integration technology, and optimal operation. In the field of functions and advanced applications, the major functions of microgrid EMS for combined heat and power (CHP) system, is described comprehensively in [7], and the software architecture and advanced application system are designed in [7], [9]. In the area of information integration technology, the common information model (CIM) extension based on IEC61970-301 is developed for the microgrid [9], [10] and the database technology based on CIM is proposed in [11]. In the area of optimal operation, the economic operation, from the aspect of electricity market, is researched in [6]-[8]. Environmental and economic operation in the microgrid is also emphatically discussed in [6], [7], [12].

New energy is abundant in many islands, and there is autonomous operation in many island power systems. Thus, new energy power supply system (NEPSS) can be built by MG technology for islands [5]. But NEPSS has three major characteristics compared to the microgrid. First, the proportion of new energy generation (NEG) is very high in the NEPSS, even close to 100% in some cases, which leads to great uncertainty of NEPSS operation and control. Second, many islands are distant from mainland, so the connection between the NEPSS and BPS is weak, or even does not exist. Thus, NEPSS is mainly operated in the autonomous mode, but the microgrid is mainly operated in the grid-connected mode [6]. Third, many small islands are exposed to more natural disasters [13], while the microgrid is operated in normal environment. Thus, reduce load loss in bad weather is an important task in the NEPSS.

Hence, NEPSS is a special microgrid. While there is the need for energy management system in NEPSS, not enough research has been carried out on NEPSS EMS. Thus, this paper mainly focuses on NEPSS EMS. The paper proposes an architecture for NEPSS EMS and describes each module in detail. Among these modules, the NEPSS dispatch plan is specifically analyzed from different perspectives. Finally, a rolling method for dispatch plan is designed.

II. Characteristics of Typical NEPSS

Fig. 1 demonstrates the typical NEPSS, which located at the end of distribution network by one 10KV line. It is assumed that the connection is weak, indicated by the dotted line. A topology structure that is proposed for typical microgrid (TM) in [8] is adopted by the typical NEPSS. The percentage in the parentheses represents the proportion of rated power of the generator to total generation capacity. Thus, the intermittent renewable energy takes up 90% of the total

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generation capacity.

Compared to BPS and TM, the typical NEPSS has many characteristics, as shown in Table I.

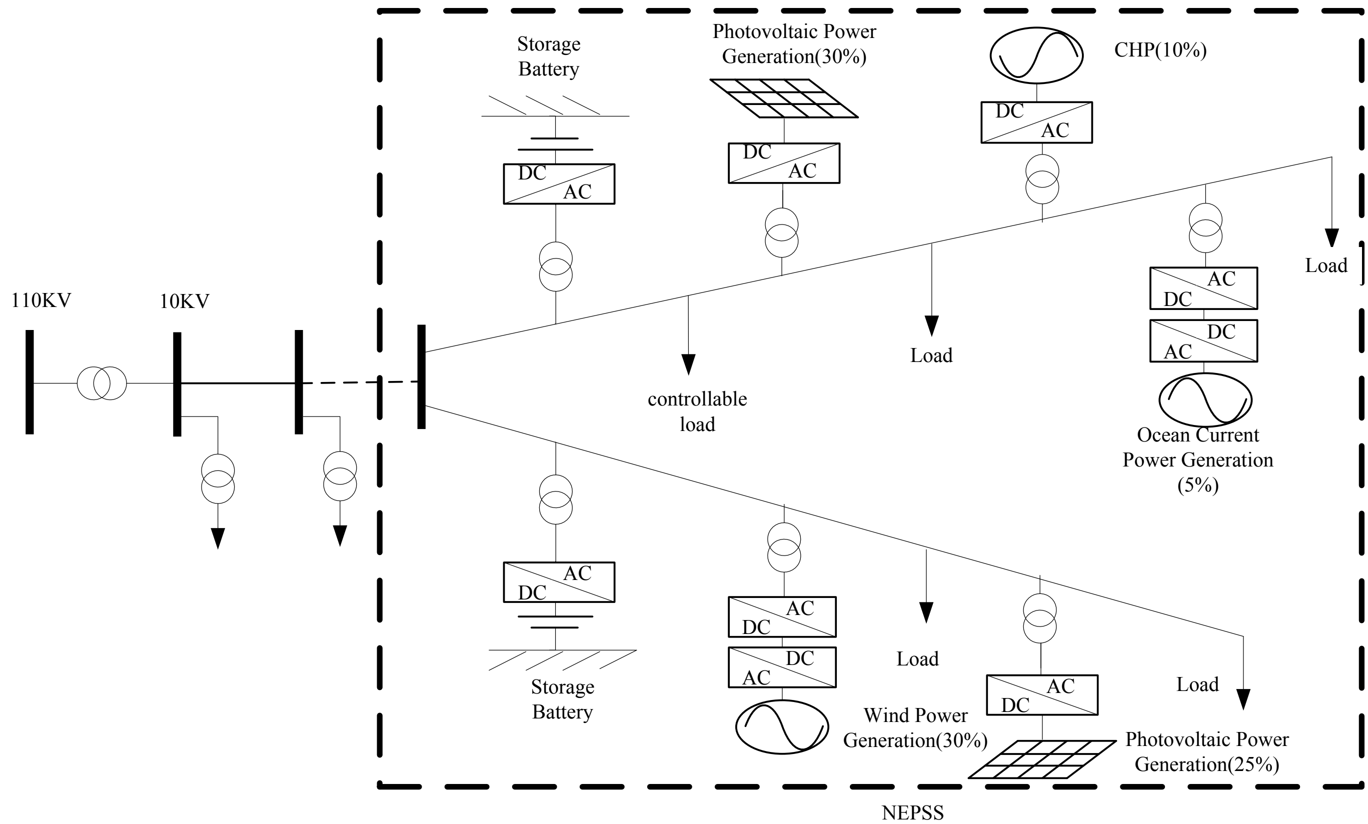

Fig. 1. Single line diagram for typical NEPSS

TABLE I
COMPARISONS AMONG NEPSS, TM AND BPS

	NEG Ratio	Energy Storage	The Highest Voltage Level	Dispatch Objects	Environment	Operation Mode
NEPSS	High	Existence	Medium Voltage (10KV in Fig.1)	Controllable generators and load, energy storage device	Frequent natural disasters	Grid-connected mode, autonomous mode dominated
TM	Moderate	Existence	380V generally	Controllable generators and load, energy storage device	Normal	Grid-connected mode dominated, autonomous mode
BPS	Very low	Negligible	220KV or higher voltage	Controllable generators	Normal	Independent operation

III. Architecture for NEPSS EMS

Architecture for NEPSS EMS is described in Fig. 2. The dispatch plan module works as the core of the architecture, incorporating with bad data identification and repair module, state estimation and pattern recognition module, load and NEG forecasting module, security early warning and protecting module, disaster assessment and disposal module, black-start decision support module. Comparisons of modules between NEPSS EMS and BPS EMS are shown in Table II.

A. Bad Data Identification and Repair Module

There may be some bad data in real-time load and weather data acquired by NEPSS SCADA due to measurement error, etc. Therefore, NEPSS EMS proposed in this paper firstly identifies bad data of load and weather data, and repairs them according to the actual situation.

There are some differences between NEPSS EMS and BPS EMS in the bad data identification and repair module, shown as follows:

- NEPSS is a very small power system. Therefore, the load curve is relatively less smooth comparing with BPS [14]. On the other hand, as NEPSS is surrounded by sea, the weather changes will have greater impact on the system, which aggravates the randomness of load variation. If bad data identification and repair methods in BPS EMS are used, repair error may be large. Therefore, special filtering algorithm is needed to eliminate such effects in the NEPSS EMS.
- Generally, NEPSS is a small radial network. Bad data

can't be identified by the layered and zoning collected data as BPS. Hence, the data preprocessing of NEPSS EMS is more difficult than that of BPS EMS, and new algorithms are needed.

- NEPSS EMS needs to identify and repair electricity load and weather data, real-time thermal load data, and cooling load data. But there is no real-time thermal load and cooling load data in BPS EMS.

B. State Estimation/Pattern Recognition Module

The major functions of state estimation module are topology error identification and operation parameters estimation, etc. This module also incorporates the bad data identification function. Even though the topology of NEPSS is simple, the high proportion of intermittent energy makes it difficult to perform state estimation.

There are three kinds of operation mode for NEPSS: grid-connected mode, autonomous mode and the transition mode between the above two modes [6], [15]. Because of the short duration, the transition mode is not considered in NEPSS EMS. The major task of pattern recognition is to identify the operation mode of NEPSS correctly. If NEPSS is operated in the autonomous mode, the module will further assess the possible running time of autonomous mode.

C. Load and NEG Forecasting Module

Renewable energy is influenced by meteorological factors, which has a strong randomness, thus the error of week-ahead forecasting or longer time is very large [17]. Therefore, the forecast cycle of NEG in the NEPSS EMS is much shorter. The forecast cycle is divided into four scales: ultra-short term (second-ahead), short term (minute-ahead), medium term (hour-ahead) and long term (day-ahead). Because load is the active side of power balance, the load forecasting cycle should be designed accordingly. The data provided by load and NEG forecasting module is the basis of security warning, dispatch planning and so on.

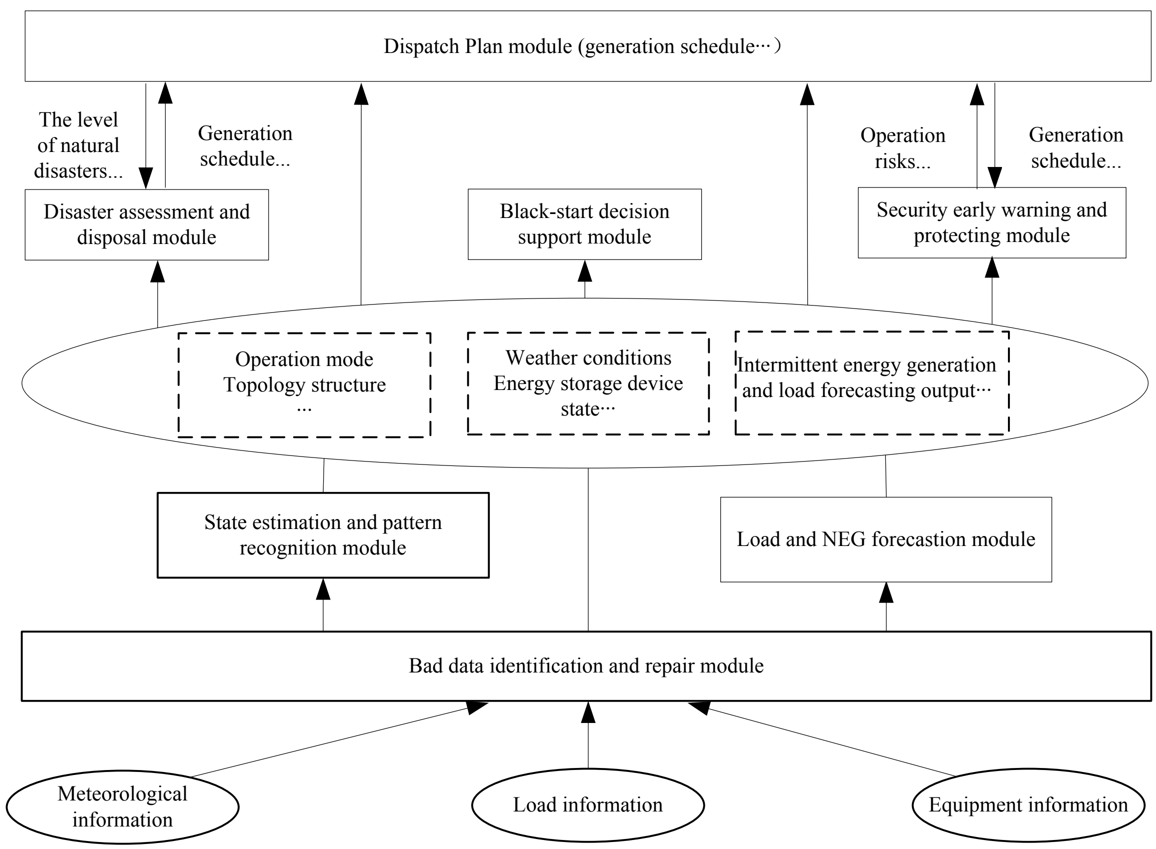

Fig.2. Architecture for NEPSS EMS

D. Security Early Warning and Protecting Module

The function of security early warning and protecting module includes operation risk assessment, and static stability & transient stability check, etc. The designed module takes into consideration line fault probability, stochastic NEG and the capacity of energy storage device when performing risk assessment. Because the occurrence of line fault has both randomness and fuzziness [18], the credibility theory is adopted to assess NEPSS operation risk, and provide the security level in the NEPSS EMS. The stability margin of autonomous mode is much smaller than that of grid-connected mode. Hence, autonomous operation of NEPSS needs faster early warning.

E. Dispatch Plan Module

As the core module of NEPSS EMS, dispatch plan module is to achieve power energy balance and help NEPSS keep stable. The task specifications are shown as follows:

- design and update the dispatch schedule under constrains of specific operating condition, the security level of system and maintenance plan.
- implement preventive control when abnormal condition appears in the system; implement emergency control when faults occur.

Compared to BPS EMS, characteristics of NEPSS EMS dispatch plan module are shown as follows:

- there are more types of resources that can be used for dispatch plan (e.g., energy storage device, CHP).
- the ratio of non-schedulable resource is high, including wind power generation, photovoltaic power generation, and ocean current power generation, etc.
- there are two dispatch modes: the grid-connected mode and autonomous mode, and they have different dispatch strategies. The duration time of autonomous operation is much longer than that of the TM. The NEPSS EMS dispatch plan will be analyzed in detail in section IV.

TABLE II
THE CONTRAST OF NEPSS EMS AND BPS EMS

		NEPSS EMS	BPS EMS
Bad Data Identification and Repair Module	Bad data processed	electrical load, weather data, cold and thermal load	electrical load, weather data
State Estimation and Pattern Recognition Module	Operation mode reorganization	Yes	No
	Consideration of random factors	Yes	No
Load and NEG Forecasting Module	Forecasting cycle	Day-ahead, hour-ahead, minute-ahead, second-ahead	Year-ahead, month-ahead, day-ahead, hour-head and minute-head.
	Forecasting objects	NEG, electrical load, cooling load, thermal load	electricity load
Security Early Warning and Protecting Module	Consideration of Stochastic NEG	Yes	No
Disaster Assessment and Disposal Module	Natural disasters assessment	Yes	Rare
	Natural disasters disposal	Yes	Rare
Dispatch Plan Module	Major Schedulable objects	Controllable generators and load, energy storage device	Controllable generators
	Dispatch modes	Grid-connected mode, island mode	Independent operation mode
	time scales	Less than one day	much longer than one day
	proportion of uncontrollable power	High	Very low
Black-start Decision Support Module	Update of start procedures renewable energy generator	Yes	No
	On-line formation	Yes	No

F. Disaster Assessment and Disposal Module

According to the state of operation, disaster assessment and disposal module evaluates weather condition and its impacts on NEPSS first, and then provides disaster level for NEPSS. If the disaster level is higher than the preset warning value, then disaster assessment and disposal module will formulate the disaster disposal strategy rapidly on the basis of real time operation condition and disaster level. Based on different operation modes, disposal methods of the same disaster level can be classified into autonomous disposal method and grid-connected disposal method. Disaster assessment and disposal module is mainly used to guarantee the power supply of the critical load in case of natural disaster (e.g., typhoon, storm).

G. Black-start Decision Support Module

When NEPSS is operated in the autonomous mode, and encounters extremely bad weather or catastrophic faults, blackout may be inevitable. After the clearing of faults, NEPSS needs to resume power supply rapidly by rational black-start scheme.

Black-start scheme must take into consideration real time NEG forecasting and the load level. A method of formulating black-start scheme for Microgrid has been proposed in [19], but the actual implementing time of each start step, especially start steps of renewable energy sources are not described in detail. In this paper, the start-up process and time of renewable energy sources are dynamically update during the process of black-start in NEPSS EMS, because of intermittency of some renewable energy sources.

IV. DISPATCH PLAN OF NEPSS EMS

In term of time horizons, dispatch plan in NEPSS can be classified into day-ahead dispatch plan, hour-ahead dispatch plan minute-ahead dispatch plan and second-ahead dispatch plan. In term of operation modes, dispatch plan NEPSS can be divided into autonomous dispatch plan and grid-connected dispatch plan, as shown in Fig. 3.

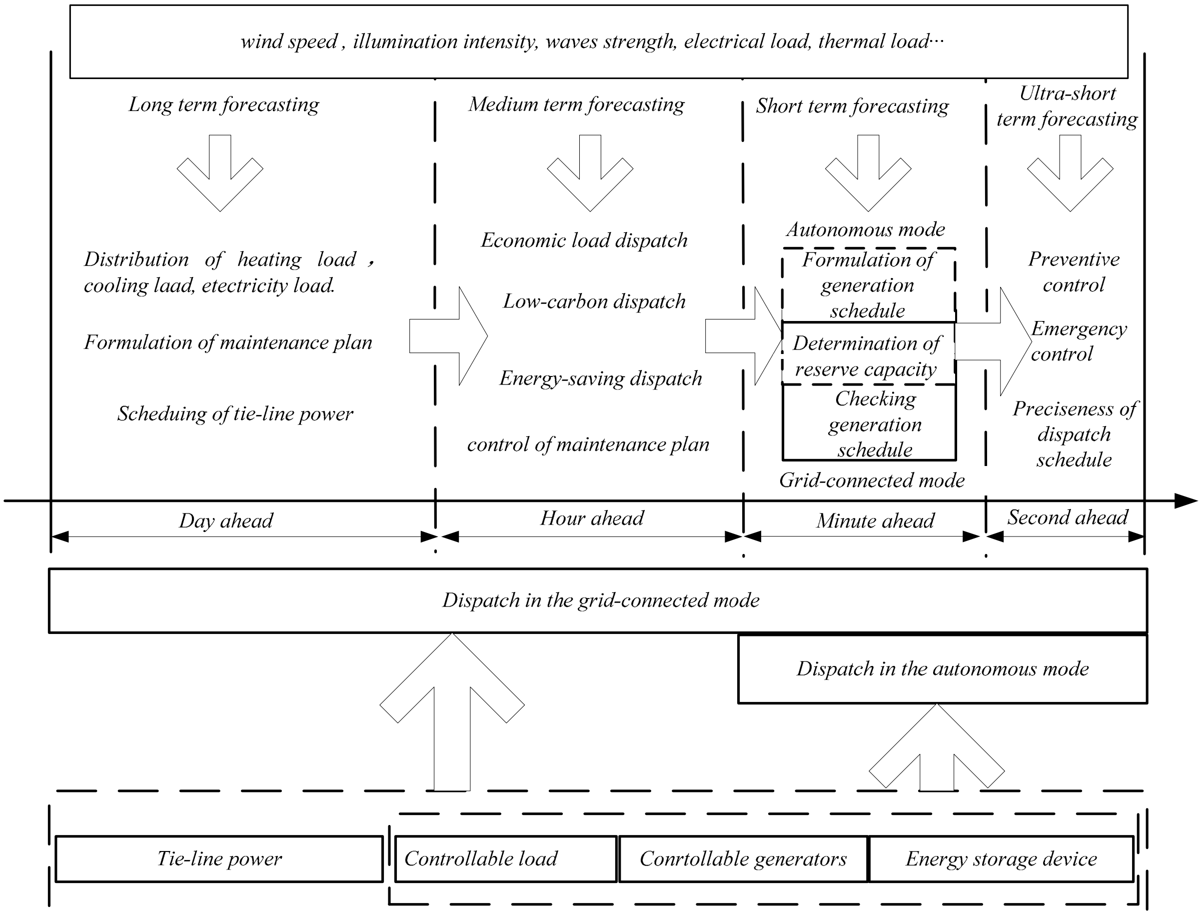

Fig. 3. Dispatch Plan of NEPSS EMS

A. Dispatch Plans of NEPSS Based on Different Time Horizons

(1) Day-ahead Dispatch Plan:

The task of day-ahead dispatch includes:

- dispatch the supply amount of power load, thermal load, cooling load for the next day;
- coordinate the tie-line power with the upstream grid;
- make maintenance plans for the next day according to the assessments of equipment condition.

Day-ahead dispatch is in the category of the grid–connected dispatch, based on long-term load and NEG forecasting results.

(2) Hour-ahead Dispatch Plan:

The major task of hour-ahead dispatch is load dispatch, based on medium term load and NEG forecasting results and the operation risk. The load dispatch can perform separate economic dispatch, low carbon dispatch, energy-saving dispatch, as well as multi-objective load dispatch which incorporates the three load dispatches above. The load dispatch method is chosen based on actual needs and public policy.

Due to the intermittency of NEG, maintenance plans made before should be modified according to the actual operation condition. Hour-ahead dispatch is also in the category of the grid-connected dispatch.

(3) Minute-ahead Dispatch Plan:

In the autonomous mode, the task of minute-ahead dispatch is mainly based on short term load and NEG forecasting results, including:

- formulate the generation schedule and check whether safety and power quality constraints.
- determine the load reserve and emergency reserve according to the state of energy storage equipments and available capacity of schedulable generators.

In the grid-connected mode, generation schedule has been made in the hour-ahead dispatch. Thus, the difference of task between grid-connected mode and autonomous mode is that there is no generation schedule formulation in the minute-ahead dispatch. Minute-ahead dispatch is very important for normal operation of NEPSS, especially in the autonomous mode.

(4) Second-ahead Dispatch Plan:

The task of second-ahead dispatch includes:

- perform preventive control to improve NEPSS security level of operation by adjusting the operating point of distributed generators, based on the safety warning information.

- take emergency measures such as shed load to guarantee power supply of critical load to the full extent, when serious faults occur,
- update the minute-ahead generation schedule by the ultra-short term load and new energy forecasting results. Because of limited life cycle of the distributed power control devices, the best time to update the minute-ahead generation schedule is only when ultra-short term load and NEG forecasting results are far different from short-term load and NEG forecasting results.

B. Dispatch Plans of NEPSS Based on Different Operation Modes

(1) Dispatch Plan in the Grid-connected Mode:

When NEPSS is operated in the grid-connected mode, reliable reference voltage and frequency can be supplied by the upstream grid [16]. Thus, NEG should be used prior to others [12]. Meanwhile, the tie-line exchange power needs to be scheduled by coordinating with the upstream grid. At the same time, maintenance plans for the next day needs to be formulated according to the condition of equipments. Based on these, economic dispatch, low-carbon dispatch, energy-saving dispatch are performed in NEPSS EMS.

In the grid-connected mode, dispatch plans consist of day-ahead dispatch plan, hour-ahead dispatch plan, minute-ahead dispatch plan and second-ahead dispatch plan with preset fixed dispatch cycle. The schedulable objects in the grid-connected mode include the tie-line, energy storage devices, controllable load, and controllable distributed generators.

(2) Dispatch Plan in the Autonomous Mode:

In the autonomous mode, there is no need to formulate power exchange plans, for NEPSS has no electrical connection with the upstream grid. Because the maintenance of equipments may increase the operation risk, maintenance plans should not be formulated under the Autonomous mode. Hence, day-ahead dispatch will be not performed in the autonomous mode.

In the autonomous mode, NEPSS has no voltage and frequency support from the upstream grid and the reserve capacity is low. Moreover, the proportion of intermittent NEG is high. Thus, keeping ISPNE safe and stable become more difficult. Therefore it is inappropriate to perform long time scale dispatches (e.g., economic dispatch, energy-saving dispatch). The most important objective of NEPSS dispatch plan is to meet critical load demand, and then other load is supplied if possible. Therefore, it's proper to design minute-ahead dispatch plan and second-ahead dispatch plan. The dispatch targeting at the autonomous mode include energy storage devices, controllable load, and controllable distributed generators.

Because of intermittent NEG, it's better to make dispatch plan with dynamic cycle in the autonomous mode. As shown in Fig. 4, if the initial cycle is T, minute-ahead dispatch plan can be made in the following way:

- firstly, determine the maximum executive time $Tmax$ based on load and NEG forecasting outputs as well as the status of energy storage device.
- secondly, if $T \leqslant Tmax$, then formulate the dispatch plan for the future T time; if $T > Tmax$, it's not feasible to formulate the dispatch plan for the future T time, indicating that the NEPSS operation stability margin is small. The program then goes to the next step; meanwhile, the operator should stay vigilant.
- thirdly, reduce the cycle of minute-ahead dispatch by (1), then, make the dispatch plan for the future T time.

$$T = k \times Tmax \tag{1}$$

In (1), k represents the curtailment coefficient, which is between 0 and 1.

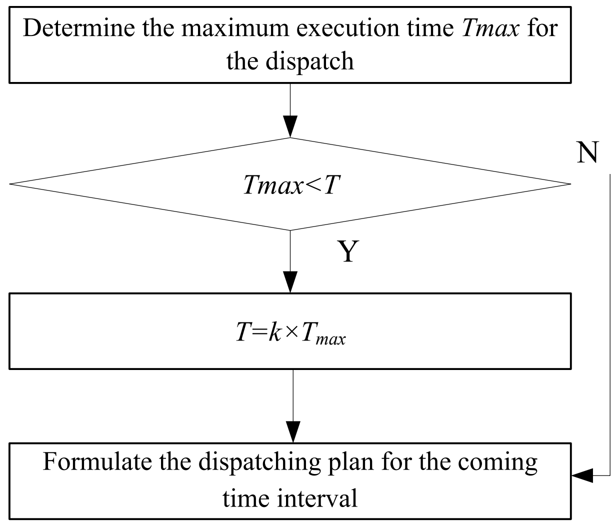

Fig. 4. Dynamic minute-ahead dispatch in the autonomous mode

V. ROLLING METHOD FOR DISPATCH PLAN

Because of bad smoothness of load curve, intermittent property of NEG and other factors, NEPSS operation condition is always in dynamic changes. Day-ahead dispatch plan and hour-ahead dispatch plan can not follow the changes exactly in real time, due to their long time horizon. Therefore, rolling dispatch strategy becomes one of the important parts of NEPSS EMS.

Based on rolling methods for dispatch plan in the smart grid [20] and power market [21], characteristics of NEPSS and ability of NEPSS EMS information processing, a dispatch plan rolling method for NEPSS is proposed as follows:

- according to load and weather characteristics of different time (e.g., whether it's peak-load or not, and whether there is day-light or not), one day is divided into several parts.
- when scheduling the hour-ahead dispatch, the hour-ahead dispatch plan is made first. Then, the estimation can be made based on the current time period and mid-term thermal/cooling load as well as the NEG generation. Day-ahead dispatch plans for the rest time can thus be updated accordingly.

- when scheduling the minute-ahead dispatch, the minute-ahead dispatch plan is made first. Then, the hour-ahead dispatch plans for the rest time are updated according to the system security level and forecasting results of load and NEG. Since the implementing time is longer than the cycle of minute-ahead dispatch, maintenance plans remain unchanged.

Day-ahead dispatch plan and second-ahead dispatch plan remain unchanged because there is no dispatch plan of which cycle is longer than one day, or shorter than one second.

VI. Conclusion

NEPSS, which takes full advantages of NEG, is a promising way to improve reliability and supply capacity of island power system. NEPSS is an important development direction of island power system.

This paper studies and proposes an architecture of NEPSS EMS. There are seven modules in the architecture, including bad data identification and repair module, state estimation and pattern recognition module, load and NEG forecasting module, security early warning and protecting module, dispatch plan module, disaster assessment and disposal module, black-start decision support module. The NEPSS EMS optimal dispatch plans is specifically designed and analyzed based on different time horizons and operation modes. Finally, a rolling method for dispatch schedule is proposed. This work can provide frames for further study of NEPSS EMS.

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VIII. Biographies

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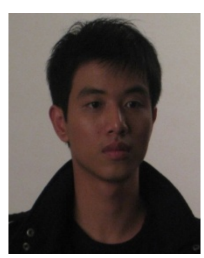

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