Proceedings

The 5th AUN/SEED-Net Regional Conference in Electrical and Electronics Engineering

International Symposium on Multimedia and Communication Technology (ISMAC) 2013

ASEAN Energy Focus

February 4-5, 2013

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The 5th AUN/SEED-Net Regional Conference in Electrical and Electronics Engineering

International Symposium on Multimedia and Communication Technology 2013 (ISMAC 2013)

ASEAN Energy Focus

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Holiday Inn Bangkok Hotel, Ratchaprasong, Bangkok, Thailand

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Department of Electrical Engineering, Chulalongkorn University, Thailand

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Optimal Scheduling of Hybrid Renewable Energy System Using MIQP Method

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Abstract— Hybrid power system combines both renewable and conventional energy as distributed generation have several advantages in optimizing renewable energy resource exploration and reducing fuel consumption of conventional generator. However, integration of renewable energy technology which is intermittent such as solar and wind power is faced on many technical and operational problems. Right operation strategy can maximize system performance and minimize generator operation cost. This paper proposes a method on short term scheduling of hybrid generating system consisting of thermal generator units, photovoltaic systems, windparks, and battery as electrical storage. The objective function of scheduling problem is to minimize fuel cost and start-up cost while satisfying all system, thermal unit, renewable unit, and battery constraints. Optimal scheduling of this hybrid thermal-renewable-battery system is formulated in Mix Integer Quadratic Programming (MIQP) model and solved using Tomlab CPLEX optimization software. Simulation on test system using 10 thermal generation units shows that this method can effectively solve scheduling problem.

I. INTRODUCTION

Implementation of renewable energy generating system such as solar and wind power recently have a great attention as an alternative beside conventional units due to their advantageous. Except that they are widely available in nature, this kind of energy can be obtained freely (no fuel cost needed) and also environmentally accepted. However, the nature of renewable energy which is intermittent makes the inclusion of renewable energy into thermal conventional units as hybrid renewable energy system (HRES) is faced on many operational problems. Optimal operation strategy of this HRES by scheduling the system should meet the demand need and satisfy all operation constraints including additional constraints related to renewable energy units.

Scheduling generating unit consist of two main related functions i.e. Unit Commitment (UC) and Economic Dispatch (ED). Committed units must meet the demand and also reserve requirement at minimum operational cost. Then the economic dispatch problem is how the load can be optimally distributed among generation units to meet power balance equation and satisfy all prevailing constraints.

This paper proposed optimal operation of hybrid renewable energy system combining thermal, renewable energy and battery units. In the previous works, many papers related optimal strategy of generation system with renewable energy resource have been published. A Dynamic Programming based approach and Genetic Algorithm was used in [1] and [2] to determine the minimum of the diesel fuel consumption in an autonomous system consisting diesel units, PV module, windpark and battery. The short-term generation scheduling problem of PV grid connected with battery is presented in [3]. In this work, scheduling with constraints of battery capacity, minimum up/down time and ramp rates for thermal units, and solar PV capacity was solved by the Augmented Lagrangian Relaxation.

On the other hand, Mix-Integer Programming (MIP) model can solve unit commitment problem accurately [6]. This method is recently more interesting because of the drastic improvements in commercial MIP solvers [7]. Some constraints can also be presented as integer or binary hence UC problem is suitable to be written in MIP. An example of Mix Integer Linear Programming (MILP) application on generation scheduling with integrating renewable energy source consisting of: PV module, windpark, fuel cell and battery is presented in [8].

In this paper Mix Integer Quadratic Programming (MIQP) model is used to solve short-term HRES optimal operation problem. The HRES in this study consist of: thermal generating units, PV system, wind power plant and battery storage.

II. GENERAL INSTRUCTIONS

A. Problem Formulation

The objective is to minimize total generation cost including fuel cost and startup cost of thermal units within Scheduling period and satisfy all operating constraint. The objective function of unit commitment problem can be formulated as

$$\min \sum_{i=1}^{T} \sum_{s=1}^{N} f_i (P_i^{T}) u_i^{s} + SU_i^{s} (1 - u_i^{s-1}) u_i^{s}$$

(1)
The index $i$ in this paper represent number of thermal generating unit, while index $t$ represent time (hour) stamp during the scheduling period ($t = 1, 2, ..., T$). Hence the term $f_i(P_{gi}^t)$ and the second term $SU^t_i$ represent fuel cost and startup cost of thermal unit $i$ at time $t$ respectively. Meanwhile $u^t_i$ represent working (on/off) status of unit $i$ at time $t$.

Fuel cost of thermal unit is expressed as a quadratic function

$$f_i(P_{gi}^t) = [a_i + b_i (P_{gi}^t) + c_i (P_{gi}^t)^2]$$

(2)

Which constant $a_i$, $b_i$ and $c_i$ is quadratic curve coefficient of fuel cost function of unit $i$ related to its power generation ($P_{gi}$).

Startup cost is is approximated with stairwise function with two discreet stairs value that represent hot start (HS) and cold start (CS) cost and is formulated as

$$SU^t_i = \begin{cases} HS_i & \text{for } T_{off,i} \leq T_{cold,i} + T_{MD,i} \\ CS_i & \text{for } T_{off,i} > T_{cold,i} + T_{MD,i} \end{cases}$$

(3)

where $T_{off,i}$ is continuously off time of unit $i$, $T_{cold,i}$ is cold start time of unit $i$ dan $T_{MD,i}$ is minimum down time of unit $i$ respectively.

B. Operation Constraints

Solution of generation scheduling problem is subject to operational constraints, 

POWER BALANCE EQUATION

Total generating power from thermal unit, renewable energy unit and battery must equal to load demand

$$P_{gi}^t + P_{gi,max}^t + P_{W}^t + P_{Bd}^t - P_{Be}^t - P_{DS}^t = 0$$

(4)

$$P_{gi}^t = \sum_{i=1}^{N} P_{gi}^t \cdot u^t_i$$

(5)

Which $P_{gi}$ is total thermal unit generation, $P_D$ is load demand, $P_{S}$ and $P_{W}$ is solar PV and wind power, then $P_{Be}$ and $P_{Bd}$ is battery charging and discharging power.

RENEWABLE ENERGY AND BATTERY PENETRATION LIMIT

Penetration of renewable and battery units to the system are limited to maximum penetration level

$$P_{gi}^t + P_{W}^t + P_{Bd}^t \leq P_{penetration, max}$$

(6)

C. Spinning reserve requirements

Spinning reserve constraint is represented as follow

$$\sum_{i=1}^{N} P_{gi, max}^t u^t_i \geq P_{D, net}^t + P_{SR}^t$$

(7)

$$P_{D, net}^t = P_D^t - (P_S^t + P_{W}^t + P_{Bd}^t - P_{Be}^t)$$

(8)

$$P_{SR}^t = R \times P_D^t$$

(9)

Available maximum power from active dispatchable unit should greater than addition of net demand ($P_{D, net}$) of thermal unit and spinning reserve requirement ($P_{SR}$). In this study renewable energy and battery unit are treated as negative load, so their generation power will substract thermal unit demand as shown in equation (7). Reserve power requirement is determined as percentage of estimated demand. It is assumed that load is vary with variability $R\%$ from load estimation.

D. Thermal unit constraints

Real power generation of thermal units should be hold between their minimum power ($P_{gi,min}$) and maximum power ($P_{gi,max}$) limit due to technical condition as formulated in equation (10)

$$P_{gi,min} \leq P_{gi} \leq P_{gi,max}$$

(10)

The thermal generating units also cannot be turned off or turned on immediately. Once a unit is committed there is a minimum up time (MUT) before the unit can be shutdown. Otherwise from off state condition the unit can be turned on only after reach it’s minimum down time (MDT). These constraints can be formulated as follow

$$T_{off,i} \geq MDT_i$$

(11)

$$T_{on,i} \geq MUT_i$$

(12)

where $T_{on,i}$ is continuously operating time of unit $i$.

E. Renewable energy unit constrains

Power from solar PV system and wind power plant are depend on weather condition and they are less than maximum potential power available.

$$P_S \leq P_{s, max}$$

(13)

$$P_W \leq P_{w, max}$$

(14)

$P_{S, max}$ is maximum available power generation from PV array. It is assumed that the value can be well predicted based on solar irradiation and temperature. The maximum available wind power ($P_{W, max}$) is also assumed can be predicted based on wind velocity data.
F. Battery constraints

Charging condition of battery is stated in state of charge (SOC). The battery energy storage level is limited between minimal (SOC$_{min}$) and maximum (SOC$_{max}$) value depend on its capacity and deep of discharge (DOD) permitted.

$$SOC_{min} \leq SOC^t \leq SOC_{max}$$ (15)

$$P_{bc}^t \leq P_{bc,max} \cdot X^t$$ (16)

$$P_{bd}^t \leq P_{bd,max} \cdot Y^t$$ (17)

$$P_{bc}^t \cdot \eta_B + SOC^{t-1} \leq SOC_{max}$$ (18)

$$P_{bd}^t \leq SOC^{t-1} - SOC_{min}$$ (19)

$$X^t + Y^t \leq 1, \quad X, Y \in \{0,1\}$$ (20)

$$SOC^t = SOC^{t-1} + P_{bc}^t \cdot \eta_B - P_{bd}^t$$ (21)

$$SOC^0 = SOC_{0}$$ (22)

$$SOC^t = SOC_T$$ (23)

In Equation 16 and 17 charging power ($P_{bc}$) and discharging power ($P_{bd}$) are limited below it’s maximum charging ($P_{bc,max}$) and maximum discharging ($P_{bd,max}$) value to ensure battery lifetime as design. Charging or discharging power also should not makes SOC level raise exceed maximum or drop below minimum value as shown in equation 17 and 18. Then equation 20 show that battery cannot simultaneously charge and discharge at the same time. Initial SOC level (SOC$^0$) and SOC at the end scheduling period (SOC$^T$) are predetermined by dispatcher. Usually dispatcher hopes that SOC level at the end period will be same with initial SOC level. Equation 21 represent energy balance in battery during charging or discharging cycle, which $\eta_B$ represent charging efficiency of the battery.

III. SIMULATION AND RESULTS

The formulated scheduling problem of HRES is then implemented on hybrid autonomous system [4] consist of 10 thermal unit, 4x360kWp PV system, 4x140 kW wind park, and battery bank.

Characteristic of thermal conventional units are shown in Table 1. Meanwhile Table 2 shows demand, PV and wind power prediction used in this simulation.

| Table 1. Thermal units characteristic |
|-------------------------------|-----|-----|-----|-----|
| **Unit number** | **P_{min} (kW)** | **P_{max} (kW)** | **a** | **b** |
| 1 | 100 | 600 | 5 | 4 |
| 2 | 100 | 600 | 5 | 6 |
| 3 | 100 | 400 | 20 | 8 |
| 4 | 100 | 400 | 20 | 10 |
| 5 | 50 | 300 | 30 | 10 |
| 6 | 100 | 300 | 30 | 12 |
| 7 | 100 | 200 | 40 | 14 |
| 8 | 50 | 200 | 40 | 16 |
| 9 | 50 | 100 | 55 | 15 |
| 10 | 50 | 100 | 55 | 17 |

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Battery have storage capacity of 2500 kWh with charging and discharging rates is limited to 500 kWh a hour, charging efficiency is assumed 95% and DOD is 60%. It is also assumed that SOC level at the end of scheduling period will be same with initial SOC level. In this work, initial SOC level is 1250 kWh. Finally penetration of renewable unit and battery is limited to 1000 kW. The simulation results of the proposed method with and without renewable-battery unit at load variability of 10% are shown in Figure 1.
As shown in Figure 1 (a), nine units should be operated to supply the forecasted demand when renewable and battery unit not considered in the scheduling process. Inclusion of renewable and battery unit will reduce thermal unit contribution and hence reduce the operational cost since solar and wind power cost is neglected. Applying battery make generation cost decrease more. Battery can store electric energy at low load condition or when renewable energy production is high. Then this storage energy will discharge when necessary to minimize thermal unit operation and it’s dispatch power.

Simulation results of this study was compared with other method using identic system and scheduling scenario [4]. In this work LR, GA and LRGA method are used to solve the scheduling problem with reserve power is determine only based on load variability of 10%. The comparation result is shown in Table 5 which MIQP give better result on both case with thermal unit only and when renewable-battery unit are included in the system. In case of generation scheduling by including thermal-renewable-battery, scheduling using MIQP method give lower generation cost by 0.91% compared with LR and LRGA method. Meanwhile, the comparison result of MIQP with GA method, MIQP method also give better result with the improvement of 0.88%.

Table 5 Comparison of generation cost with other methods

<table>
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<th>Cases</th>
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IV. CONCLUSIONS

This paper has presented a method for generation scheduling of a hybrid renewable energy system integrating renewable energy generating units in the thermal conventional generating system. The proposed method based on MIQP formulation model was tested on a system including ten thermal generating units, PV module, wind plant, and battery unit. The simulation results show that the proposed method can solve the scheduling problem with better result compared with LR, GA and LRGA methods.

REFERENCES