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Multi-Objective Optimal Operation Considering Voltage Stability for Unit Commitment

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Abstract. Nowadays renewable energy is becoming very familiar by providing a lot of benefits in the power system as well as environment. However, renewable generations like Photovoltaic (PV), Wind generation (WG) output power depends on the weather conditions that causes power generation uncertainly because changing weather condition determines the output power of the renewables generation. As we know, most of electric power companies have been introduced renewable energy that will increase the power system uncertainty simply. Therefore, it is predicted that this uncertainty will increase the likelihood of voltage instability and voltage collapse. On the other hand, renewable energies have great contribution to save power producer from completion by reducing per unit operation cost. Electric unity company requires to an optimal operation to maximize the profit that is why Unit Commitment (UC) becomes an important issue in recent decade. Also, fluctuations in supply and demand are increased by the introduction of renewable energy. Thus, we suggest the optimal operation method of the generator and the energy storage for Unit Commitment by considering the voltage stability in this research. Besides, a battery storage system has been proposed by using this devices, the power fluctuation can be reduced. The effectiveness of the proposed method is verified by simulation results in the Matlab/simulink.

Key words
security constrained unit commitment, voltage stability, optimal power flow, energy storage system, photovoltaic generation.

1. Introduction

In recent years, industrial development increases the demand of electricity. Due to full fill increasing demand of electricity, power producers produce electricity by using different kinds of fuels that increasing the per unit electricity tariff. In consequence, electric enterprises are required to maximize profits by reducing the per unit cost. Therefore, Unit Commitment (UC) has become an important issue. Moreover, due to more efficient use of transmission lines most of the unit of the power systems should be operated near voltage stability limits. As a result, a drop in a system voltage and possibility of voltage

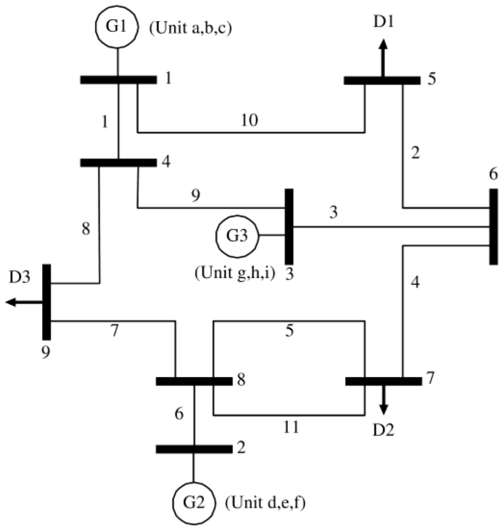

Fig.1 Modified IEEE 9-bus system.

collapse are increased. In the study of various conventional UC techniques and methods are used such as Priority List, Mixed integer programming, and Lagrangian relaxation method. Method considers the voltage stability, bus voltage and reactive power constraints which are difficult thing to solve. Something has been reported on UC by considering voltage stability. In the future, the UC in consideration of voltage stability and transmission network constraints will become necessary because the limitations of the power system will increase and became complicated by the introduction of power liberalization. A lot of researches had been done on single objective optimization in before but very few researches had been committed on multi-objective optimization[1-5]. In this research, the optimal power flow has been calculated. An optimal operation method based on the generators starting and stopping with considering of the transmission network constraints and voltage stability has been proposed. Due to large number of penetration of photovoltaic (PV), conventional load curve is become, duck shape curve, this curve's peak

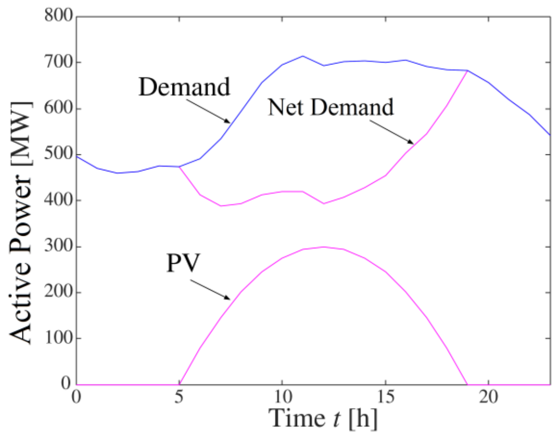

Fig. 2. Daily load curves.

Table I. – Line parameters.

Line No.	r[pu]	x[pu]	Line capacity [MVA]
1	0.0192	0.0576	250
2	0.0577	0.1700	150
3	0.0195	0.0586	300
4	0.0336	0.1008	150
5	0.0240	0.0720	250
6	0.0208	0.0625	250
7	0.0537	0.1610	250
8	0.0283	0.0850	250
9	0.0283	0.0850	250
10	0.0537	0.1610	250
11	0.0283	0.0850	250

load and off peak load have been levelled by using a storage battery. It helps to reduce the transmission loss, minimize operation cost, and conforms the optimum operation of the power system. In addition, it will be clear from this research that the uses of the electric power which needs to maintain voltage stability in every time by considering voltage uncertainty. Due to transmission loss minimizing, and operational cost minimizing, a multi-objective optimization method with considering genetic algorithm has been used in this paper. The effectiveness of the proposed method, we have verified by using MATLAB / SIMULINK.

2. System Model

The power system model and load demand curve are shown in Figs. 1 and 2 accordingly. Fig. 2. shows the PV output power and load demand. Here, it can be seen that the load demand has been changed by a large number of the PV penetration. Energy storage unit (864MWh) with the initial 30% state of charge (SOC) is connected to power systems for Case 3. The power system parameters are presented in Tables I and II.

Table II. – Generator parameters.

Unit No.	a	b	c	d
P_{max}[MW]	162	55	55	130
P_{min}[MW]	25	10	10	20
a[\$/h]	450	665	670	700
b[\$/MWh]	19.70	27.27	27.79	16.60
c[\$/MW^{2}h]	0.00398	0.00222	0.00173	0.00200
T^{on}[h]	6	1	1	5
T^{off}[h]	6	1	1	5
SUC[\$]	1800	60	60	1100
Initial state[h]	6	−1	−1	5
Unit No.	e	f, h	g	i
P_{max}[MW]	80	85	130	55
P_{min}[MW]	20	25	20	10
a[\$/h]	370	480	680	660
b[\$/MWh]	22.26	27.74	16.50	25.92
c[\$/MW^{2}h]	0.00712	0.00079	0.00210	0.00413
T^{on}[h]	3	3	5	1
T^{off}[h]	3	3	5	1
SUC[\$]	340	520	1120	60
Initial state[h]	−3	3	5	−1

3. Optimization Problem Formulation

A. *Objective function*

Eq. (1) is the transmission loss of the day. Eq. (2) is the operating cost.

$$Min\sum_{t=1}^{NT}\sum_{i=1}^{l} LOSS_i \tag{1}$$

$$Min\sum_{t=1}^{NT}\sum_{j=1}^{NG} FC_j(PG_j(t)) + SUC_j(t) \tag{2}$$

where, $LOSS_i$, $FC_j(PG_j(t))$, $SUC_j(t)$, NT, l, and NG are transmission loss of the transmission line i, generation cost for unit j at time t, start up cost of unit j at time t, number of scheduling hours, number of transmission lines and number of generating units, respectively. The nonlinear cost functions of generating units are shown in Eq. (3).

$$FC_j(PG_j(t)) = a_j + b_j PG_j(t) + c_j PG_j^2(t) \tag{3}$$

where, FC_j, PG_j (t) , a_j, b_j, and c_j are fuel cost for unit j, active power output for unit j at time t, fuel cost coefficients for unit j , accordingly.

B. *Constraints*

Constraints that are introduced in this paper are given in the following equations.

1) Generator effective power output constraint

$$PG_i^{\min} \le PG_i(t) \le PG_i^{\max} \tag{4}$$

$$QG_i^{\min} \le QG_i(t) \le QG_i^{\max} \tag{5}$$

where, PG_i^{min}, PG_i^{max}, QG_i^{min}, QG_i^{max} are lower limits for active power generation unit *i*, upper limits for active power generation unit *i*, lower limits for reactive power generation unit *i*, upper limits for reactive power generation unit *i*, correspondingly.

2) The Min-up and Min-down time constraints

$$T_i^{on} \le X_i^{on}(t) \tag{6}$$

$$T_i^{off} \le X_i^{off}(t) \tag{7}$$

where, T_i^{on}, T_i^{off}, $X_i^{on}(t)$, $X_i^{off}(t)$ are on- and off-time limits Unit *i*, on- and off-time of Unit *i* at time *t*, respectively.

3) AC power flow equation constraint

$$PG_i - PL_i = V_i \sum_{k=1}^{N} V_k \left\{ G_{ik}\cos(\theta_i - \theta_k) + B_{ik}\sin(\theta_i - \theta_k) \right\} \tag{8}$$

$$QG_i - QL_i = V_i \sum_{k=1}^{N} V_k \left\{ G_{ik}\sin(\theta_i - \theta_k) - B_{ik}\cos(\theta_i - \theta_k) \right\} \tag{9}$$

where, PG_i, QG_i, *i*, PL_i, QL_i, θ_i, G_{ik}, and B_{ik} are active and reactive powers are produced by generator *i*, active and reactive powers are consumed by demand *i*, voltage angle in Bus *i*, real and imaginary part of the *ik* elements of the node admittance matrix, respectively.

4) Bus voltage constraints

$$0.9\text{pu} \le V_i(t) \le 1.1\text{pu} \tag{10}$$

where, $V_i(t)$ is voltage of Bus *i* at time *t*.

5) Power transmission line capacity constraints

$$S_{line}(t) \le S_{line}^{\max} \tag{11}$$

where, $S_{line}(t)$ is active power flow of *line* at time *t*.

6) Storage battery constraints

$$C_{ES}^{\min} \le C_{ES}(t) \le C_{ES}^{\max} \tag{12}$$

$$0 \le \left| P_{ES}(t) \right| \le P_{ES}^{\max} \tag{13}$$

$$C_{ES_i}(t) = \begin{cases} C_{ES_i}(t-1) - P_{ES_i}(t) / \eta & (P_{ES_i}(\mathrm{t}) > 0) \\ C_{ES_i}(t-1) - P_{ES_i}(t) \cdot \eta & (P_{ES_i}(\mathrm{t}) < 0) \end{cases} \tag{14}$$

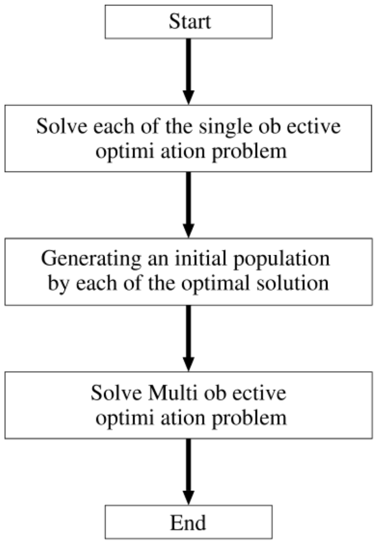

Fig. 3. Flowchart of the method.

where, C_{ESi}, P_{ESi} and η are the capacity of energy storage system *i*, the power of energy storage system *i*, efficiency of energy storage system, accordingly.

7) Voltage stability constraints

$$0.5\text{pu} \le \left\{ \Delta P_{\min}(t),\ \Delta Q_{\min}(t) \right\} \tag{15}$$

where, $\Delta P_{\min}(t)$ and $\Delta Q_{\min}(t)$ are voltage stability[6] in the stability index of the lowest transmission line at time *t*.

4. Optimum operation method

In this study, to solve UC in accordance with the procedure is shown in Fig. 3. First, the single objective optimization problem has been solved for minimizing the transmission losses, then minimizing the operational cost correspondingly. In this case, the generator will be stop when the generator output is below the minimum output, determined by activated if it exceeds It reduced the variable. Thus, to satisfy the large number of constraints, you can search for a better solution. A multi-objective optimization as an optimization method by using genetic algorithm of MATLAB Optimization Toolbox.

5. Simulation Result

The simulation conditions of each case is presented Table III. Fig. 4 shows the pareto optimal solution for each case. From Fig. 4, the variation width of the pareto optimal solution of transmission loss is narrowed and operating cost is become large. Therefore, a solution has been selected that operating cost becomes minimum among the respective pareto optimal solutions. It is compared the simulation results for each case. Figs. 5-7 shows a UC which obtained a solution that is selected from the Pareto optimal solutions for each case in Fig. 4. Fig. 8 shows the voltage stability index, obtained a solution selected from the pareto optimal solutions for each case in Fig. 4. It shows a comparison of the system load in case of with/without using a ESS in Table IV.

Table III. – Simulation conditions.

Case	Simulation conditions
1	Optimal operation of the generator 9 unit
2	Connect the PV to the Bus 5, 7, 9 optimal operation
3	In addition to Case 2, connect the ESS to the Bus 9 optimal operation

Table IV. – Comparison of system load without and with ESS.

	Without ESS	With ESS
Peak load [MW]	683.5	633.8
Lowest load [MW]	351.9	384.8
Peak-valley Ratio	1.94	1.64
Average load [MW]	488.6	482.8
Load factor [%]	71.48	76.19

Compared to Case 1 from Fig. 4, Case 2, by the PV is a large amount penetration, it can be seen that the operational costs, transmission losses can be greatly reduced. In addition, the storage battery is also introduced in Case 3. Further operations for a minimum of operating costs and transmission loss can be achieved.

Fig. 6(Case 2), shows the unit commitment program in duck shape curve. Fig. 7 shows a storage battery has been introduced in the power system for getting minimum start-up cost benefit. Fig. 8, discloses the voltage stability for Cases 1, 2 and 3. Table III, displays the simulation conditions for different cases like Cases 1, 2 and 3. By performing the optimum charge and discharge of a storage battery the operating costs can be minimized. It is understood that it can respond to the duck curve problems.

Also, it can be seen that the system operation based on the generator starts and stops through maintaining the voltage stability in each case than Fig. 8 can be achieved.

6. Conclusion

In this research, using a multi-objective optimization method based on genetic algorithm has been proposed. On behalf of minimizing the operation cost and transmission loss this research has been proposed. Duck curve problem by mass introduction of PV from simulation results it was possible to be eliminated by the storage battery. Further it was to determine the best investment based on UC that achieves power transmission loss and operating cost minimization. Furthermore, in each case by considering voltage stability constraints, it is shown that it is possible to realize the operation of the power system to improve the voltage stability.

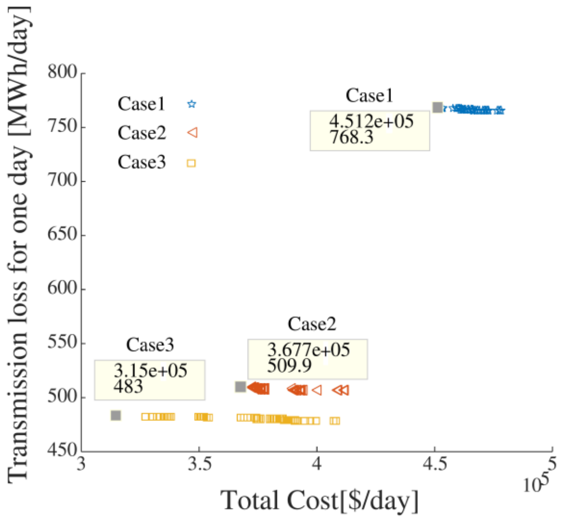

Fig. 4. Paeto front for different cases.

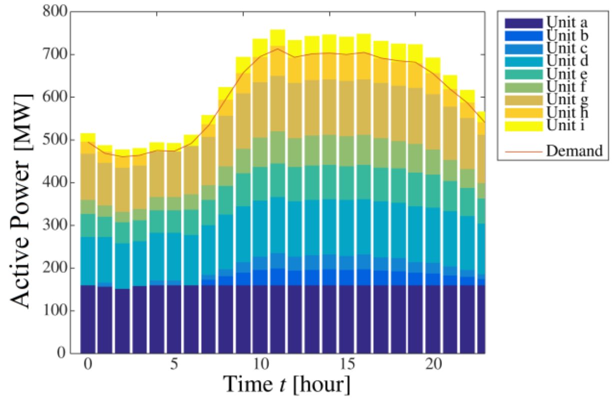

Fig. 5. Unit Commitment(Case 1).

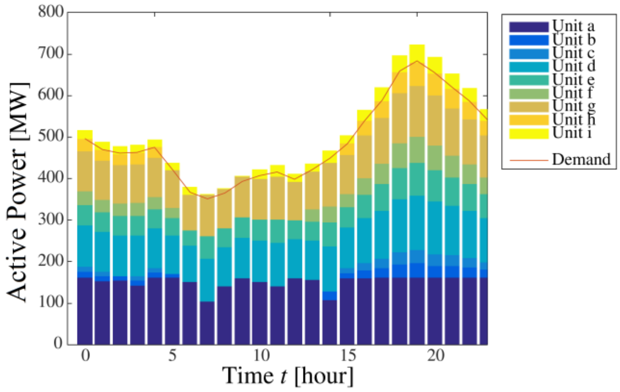

Fig. 6. Unit Commitment(Case 2).

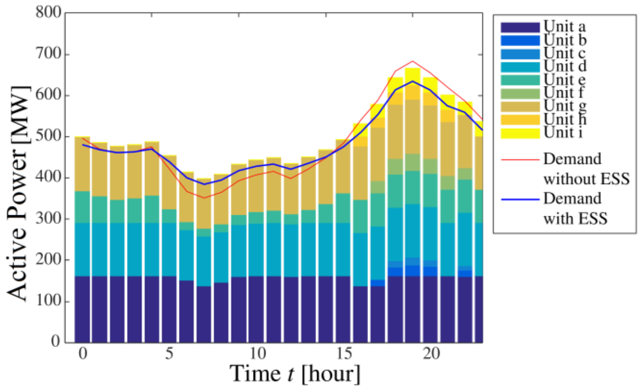

Fig. 7. Unit Commitment(Case 3).

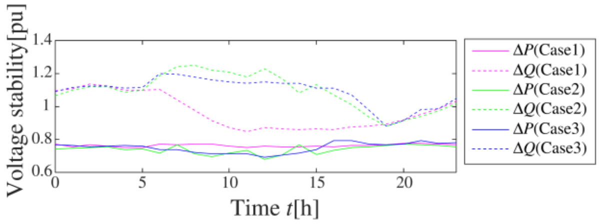

Fig. 8.Voltage Stability.

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