Another Market Simulator (AMS)

User Manual

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1. INTRODUCTION

The Another Market Simulator (AMS) is a Python-based, power market simulation package which has been integrated into the CURENT large-scale testbed (LTB). The CURENT LTB is an open-source software-based platform which functions as a “digital twin” to simulate power system operations with emulated communication networks, energy management systems, and control applications.

AMS is the market module of the CURENT LTB for solving steady-state market clearing and scheduling problem. The AMS package (beta test version) is available on:

https://github.com/qzhang41/LTB_Market

1.1 Maintenance & Support

For software maintenance and support, please contact Professor Fran Li at fli6@utk.edu.

1.2 AMS Development

The current version of AMS is capable of solving three types of problems: (1) unit commitment, (2) economic dispatch, and (3) real-time ex-post pricing. The mathematical model formulation is presented in detail in the next section.

2. BACKGROUND AND PROBLEM FORMULATION IN AMS

2.1 Economic Dispatch

Economic dispatch (ED) is the short-term determination of the optimal output of a number of electricity generators, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. Although ED with full ACOPF network formulation is the most accurate, practical power market usually rely on DCOPF for its convexity. The economic dispatch model implemented in AMS uses the DCOPF formulation. The voltage magnitudes and reactive powers are eliminated from the problem formulation, and real power flows are modeled through generations shift factors (GSF). A typical ED model is shown in (1)-(5). The objective is to minimize the operation cost. Equations (2)-(5) include the power balance constraint, unit capacity constraints, and line flow limits.

$$\min \sum_i C_i(P_i) \quad (1)$$

$$\sum_i P_i - d = 0 \quad (2)$$

$$P^{\min}{}_i \le P_i \le P^{\max}{}_i, \forall i \in N_b \quad (3)$$

$$\sum_{i=1}^{N_b} GSF_{l-i}(\mathrm{P}_i - D_i) \le \mathrm{F}_l^{\max} \forall l \in L \quad (4)$$

$$\sum_{i=1}^{N_b} GSF_{l-i}(\mathrm{P}_i - D_i) \ge F_l^{\min} \forall l \in L \quad (5)$$

$$LMP_i = v - \sum GSF_{l-i}\kappa^+{}_l + \sum GSF_{l-i}\kappa^-{}_l \quad (6)$$

An important outcome of the ED model is the locational marginal price (LMP). The LMP pricing scheme has been widely adopted in the U.S. electricity markets to provide economic signals to market participants. LMPs are defined as the marginal increase in dispatch costs versus the marginal increase in load consumption at a particular bus, as given in (6). Lagrange multipliers are assigned to each constraint to formulate the Lagrange function. The LMP at bus *i* is defined as the effect of incremental load on the cost function. The detail of model (1)-(6) can be found in [1].

2.2 Unit Commitment

Unit commitment (UC) is the process of deciding when and which generating units at each power station to start-up and shut-down economically and reliably. The UC model implemented in AMS also use the DCOPF formulation. The objective function (7) includes the no-load cost, start-up cost, shut-down cost, and operation cost. Equations (8), (9), and (11) include the power balance constraint, unit capacity constraints, and line flow limits. Equation (10) and (12)-(14) represents ramping constraints, minimum down time constraint, minimum up time constraint, and the state shifting constraint. The detail of model (7)-(14) can be found in [2].

$$\min \sum_i \sum_t C_{i,t}^{up} \times s_{i,t}^{up} + C_{i,t}^{down} \times s_{i,t}^{down} + C_{i,t}^{N} \times x_{i,t} + C_i(p_{i,t}) \quad (7)$$

$$\sum_i p_{i,t} - d_t = 0 \quad \forall t \in T \quad (8)$$

$$P_{i,t}^{\min} \times x_{i,t} \le p_{i,t} \le P_{i,t}^{\max} \times x_{i,t} \quad \forall t \in T \ \forall i \in I \quad (9)$$

$$ramp_{i,t}^{D} \le p_{i,t} - p_{i,t-1} \le ramp_{i,t}^{U} \quad \forall t \in T \ \forall i \in I \quad (10)$$

$$-F_l^{Lim} \le \sum_i GSF_{l-i} \times (p_{i,t} - d_{i,t}) \le F_l^{Lim}, \quad \forall t \in T \quad \forall l \in L \quad (11)$$

$$\sum_{i=t-UT_i+1}^{t} s_{i,t}^{up} \le x_{i,t} \quad \forall t \in T \ \forall i \in I \quad (12)$$

$$\sum_{i=t-DT_i+1}^{t} s_{i,t}^{up} \le 1 - x_{i,t-DT_i} \quad \forall t \in T \ \forall i \in I \quad (13)$$

$$x_{i,t} - x_{i,t-1} = s_{i,t}^{up} - s_{i,t}^{down} \quad \forall t \in T \ \forall i \in I \quad (14)$$

2.3 Two-settlement market-clearing

The U.S. wholesale electricity markets generally implement the two-settlement market-clearing process, which consists of day-ahead (DA) and real-time (RT) markets. The offers and bids from generator companies and load aggregators are collected by ISOs. UC and ED problems are solved to determine DA unit dispatches and LMPs. DA LMPs are calculated based on 24-hour advance load forecasting. The purpose of the RT market is to offer adjustments for load forecasting differences between RT and DA.

The AMS has implemented the two-settlement market-clearing process for market studies. The DA market model will run the UC model to determine the unit status, and the ED model will be solved to determine the DA dispatch and clear the market. The UC and ED models are presented in above two subsections.

The real-time market-clearing model in AMS is implemented as ex-post model. The generation dispatches are calculated based on the forecasted conditions for the next trading period. The price is settled in a near real-time estimate. The ex-post model formulation is shown in (15)-(19) [3].

$$\min \sum_{i}^{N_g} c_i(\Delta \mathrm{P}_{gi}) - \sum_{j}^{N_d} \mathrm{d}_j(\Delta \mathrm{P}_{dj}) \tag{15}$$

$$\sum_{i}^{N_g} \Delta \mathrm{P}_{gi} = \sum_{j}^{N_d} \Delta \mathrm{P}_{dj} \tag{16}$$

$$\sigma P_{gi}{}^{\min} \le \Delta P_{gi} \le \sigma P_{gi}{}^{\max} \tag{17}$$

$$\sum_{k=1}^{N_b} GSF_{l-k}(\Delta \mathrm{P}_{gk} - \Delta \mathrm{P}_{dk}) \le \sigma \mathrm{F}_l^{\max}, \forall l \in L^+ \tag{18}$$

$$\sum_{k=1}^{N_b} GSF_{l-k}(\Delta \mathrm{P}_{gk} - \Delta \mathrm{P}_{dk}) \ge \sigma \mathrm{F}_l^{\min}, \forall l \in L^- \tag{19}$$

3. TUTORIAL EXAMPLES

3.1 Economic Dispatch

The following is an example of running an ED problem on the PJM 5-bus system by AMS. The AMS model use the same input file as Matpower [4].

Table I. Input commands

Function	Command
ED	-ED “AMS\data\case5.m"
ED with multi-	-ED “AMS\data\case5.m" -L “AMS\data\load_profile.m"

period load profiles	

Table II. Input options

Command	Meaning
-ED	To perform ED
-L	To specify the load

The output command is shown in Table III. AMS can output the ED results into a .xlsx file. The dispatch results and LMPs are stored in two sheets separately. AMS can also plot the LMPs as shown in Fig. 1.

Table III. Output options

Function	Command
Output the ED results to .xlsx file	-ED “AMS\data\case5.m" -OUT 1
Plot the ED results	-ED “AMS\data\case5.m" -OUT 2

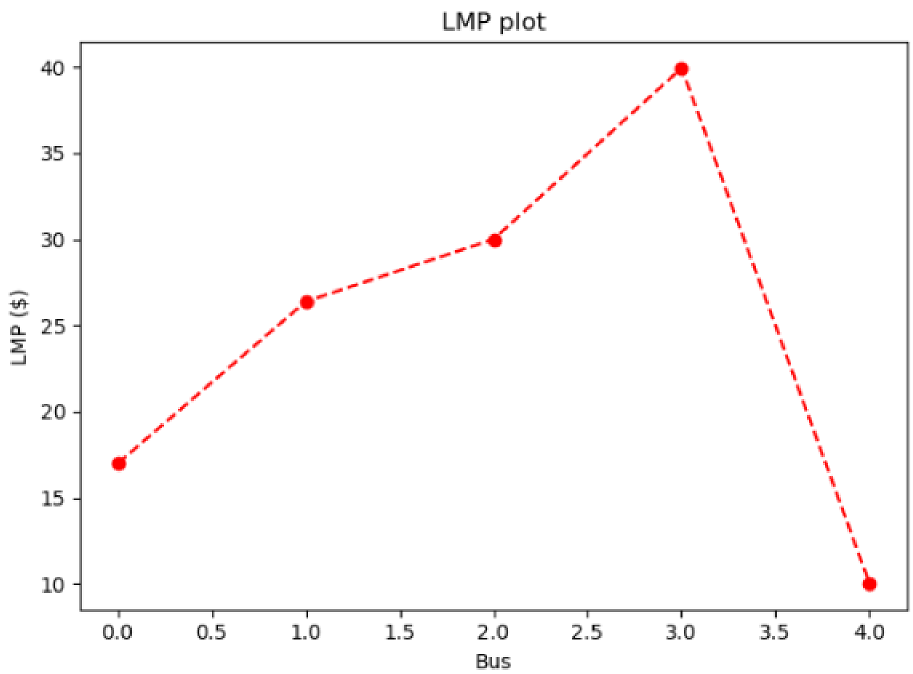

Fig. 1 LMP plot of PJM 5-bus system by AMS

3.2 Unit Commitment

The following is an example of running an UC problem on the IEEE 14-bus system by AMS. For the UC problem, AMS needs three input files: (1) system file; (2) generator profile; (3) load profile. The three input files are similar to the input file of Matpower MOST tool.

Table IV. Input commands

Function	Command
UC	-UC "AMS\data\tcase14.m" -L " AMS\data\load_profile.m" -XGD " AMS\data\ex_xgd_uc.m

Table V. Input options

Command	Meaning
-UC	To perform UC
-L	To specify the load profile
-XGD	To specify the generator profile

The output command is shown in Table III. AMS can output the UC results into a .xlsx file. The generator commitment results and dispatches are stored in two sheets separately. AMS can also plot the commitment and dispatches as shown in Fig. 2.

Table VI. Output options

Function	Command
Output the UC results of unit 1 to .xlsx file	-UC "AMS\data\tcase14.m" -L "AMS\data\load_profile.m" -XGD "AMS\data\ex_xgd_uc.m" -OUT 1 -PU 1
Plot the UC results of unit 1	-UC "AMS\data\tcase14.m" -L "AMS\data\load_profile.m" -XGD "AMS\data\ex_xgd_uc.m" -OUT 2 -PU 1

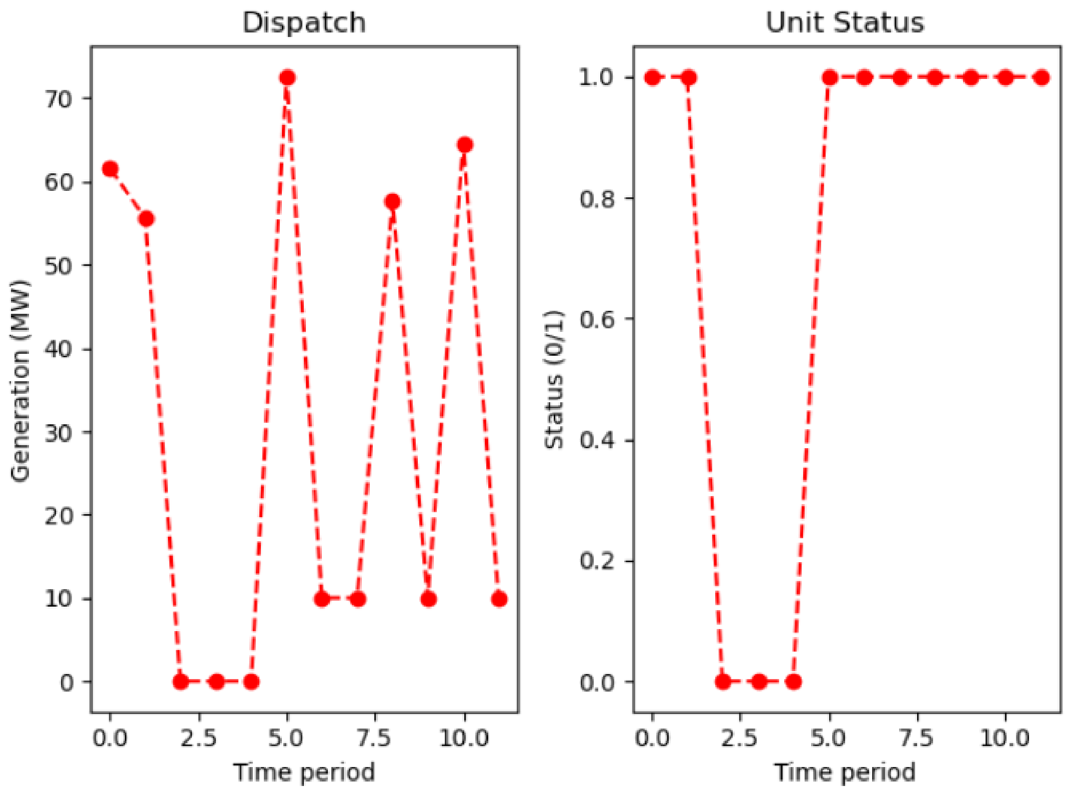

Fig. 2 UC results plot of IEEE 14-bus system by AMS

3.3 Two-settlement market-clearing

The two-settlement market-clearing consists of DA and RT markets.

(1) DA market-clearing

The DA market-clearing function in AMS will perform the UC according to the given load profile first. Then, ED problem is solved period to period with the unit status fixed to the solved UC status.

Table VII. Input commands

Function	Command
DA	-DA "AMS\data\tcase14.m" -L " AMS\data\load_profile.m" -XGD " AMS\data\ex_xgd_uc.m

Table VIII. Input options

Command	Meaning
-DA	To perform DA market-clearing

(2) RT market-clearing

The RT market-clearing function in AMS will perform the multi-period ED according to the given load profile first representing the ex-ante results. Then, a disturbance file is parsed to represent the RT disturbance. In the end, the ex-post model is solved at each period.

Table VII. Input commands

Function	Command
RT	-RT "AMS\data\tcase14.m" -L " AMS\data\load_profile.m"

Table VIII. Input options

Command	Meaning
-RT	To perform RT market-clearing

3.4 Additional Functions

The following two functions are still under developments.

(1) Geographical visualization

AMS is the market module of LTB, and it will connect with the geographical visualizer in LTB.

(2) False data injection attack (FDIA) impact analysis

The disturbance file for the RT clearing will be implemented with FDIA functions [5].

4. Data Format

4.1 Input Data

AMS uses the same format as Matpower and Matpower MOST.

(1) System topology

Bus data: Bus_id Type Load

Generator data: Bus_id Status Pmax Pmin Ramp30

Branch data: F_bus_id T_bus_id r x b Rating

Generator cost: Startup Shutdown Type a b c

(2) Generator profile

Generator profile: CommitKey MinUp MinDown

(3) Load profile

The load profile in AMS is slightly different from MOST. AMS has an additional section for users to specify the load participation factors.

Load profile: Type Load_level Factor

4.2 Output Data

For UC and ED, AMS will output the simulation results to .xlsx file.

(1) Output format for UC

Fig. 3 and Fig. 4 show an example of UC results output file. The y-axis represents the unit number, and the x-axis represents the time periods. The output file has two sheets. The first sheet (Fig. 3) is the power generation for each unit at each period, and the second sheet (Fig. 4) is the unit status each unit at each period.

	0	1	2	3	4	5	6	7	8	9	10	11
0	62.4	62.4	4	62.4	40	62.4	20	35	62.4	5	62.4	22
1	61.6	55.6	0	0	0	72.6	10	10	57.6	10	64.6	10
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	10	10	10	62.6	10	10	10	10	10	10	10	10

T_pg T_status

Fig. 3 UC dispatch output file format by AMS

	0	1	2	3	4	5	6	7	8	9	10	11
0	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	0	0	0	1	1	1	1	1	1	1
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	1	1	1	1	1	1	1	1	1	1	1	1

T_pg T_status

Fig. 4 UC unit status output file format by AMS

(2) Output format for ED

Fig. 5 and Fig. 6 show an example of ED results output file. The y-axis represents the bus number. The output file has two sheets. The first sheet (Fig. 5) is the LMP value for each bus, and the second sheet (Fig. 4) is the unit status each unit at each period.

	LMP
0	16.97736
1	26.38446
2	30
3	39.94274
4	10

LMP Dispatch

Fig. 5 LMP output file format by AMS

	Dispatch
0	40
1	170
2	323.4948
3	0
4	466.5052

LMP | Dispatch

Fig. 6 Dispatch output file format by AMS

APPENDICES

Appendix A : NOMENCLATURE

SC	Start-up cost
NLC	No-load cost
C	Generation cost function
D	Load at a specific bus
d	Total load
F^{max}, F^{min}	Upper and lower transmission capacity
$GSF_{l\text{-}i}$	Generation shift factor matrix
P^{max}, P^{min}	Upper and lower generation capacity
$s_{i,t}$, $x_{i,t}$	Start-up decision and status
P_i	Generation of unit *i*
ΔP_i	A hypothetical incremental generation of unit *i*
ΔD_i	Dispatch loads
v	Lagrange multiplier for power balance constraint
κ^+_l, κ^-_l	Lagrange multipliers for transmission capacity constraints
η^+_i, η^-_i	Lagrange multipliers for generator capacity constraints

Appendix B : REFERENCES

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