Synthetic 33-Bus Microgrid: Dynamic Model and Time-Series Parameters

Tong Han

I. Introduction

This report provides the detailed description of the synthetic 33-bus microgrid (MG), including its structure, dynamic models, and time-series parameters of loads and generations. The network structure is adapted from the IEEE 33-bus distribution network, with additional converter-interfaced renewable energy resources and energy storage systems. Time-series parameters is generated based on the open-source ARPA-E PERFORM datasets [1].

II. Basic structure

The single-line diagram of the 33-bus MG is shown in Fig. 1. The entire MG contains 23 loads, and 9 converter-interfaced generations, named G1 to G9, including 3 wind generators, 2 solar panel generators, and 4 energy storage systems.

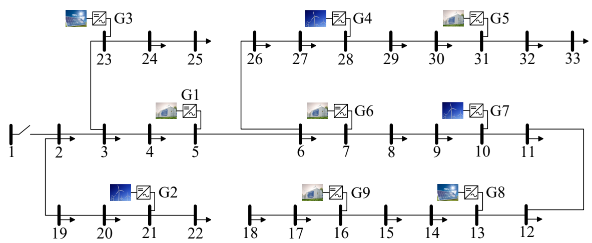

Fig. 1. Diagram of the synthetic 33-bus microgrid.

III. Dynamic Model with hierarchical control and renewable uncertainties

A. Converter model

The dynamics of the converters with hierarchical control, also including renewable uncertainties, can be formulated as below:

$$\boldsymbol{\omega} = \omega^* - \boldsymbol{K}_{\mathrm{p}}(\boldsymbol{P} - (\boldsymbol{P}^* + \boldsymbol{\xi})) + \boldsymbol{u}_{\mathrm{p}} - \omega_{\mathrm{ref}} \tag{1a}$$

$$\sqrt{(\boldsymbol{v}_{\mathrm{od}}^*)^2 + (\boldsymbol{v}_{\mathrm{oq}}^*)^2} = \boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}} \tag{1b}$$

$$\dot{\boldsymbol{\delta}} = \boldsymbol{\omega} - \omega_{\mathrm{n}} \tag{1c}$$

$$\dot{\boldsymbol{P}} = \omega_{\mathrm{c}}(-\boldsymbol{P} + \boldsymbol{v}_{\mathrm{od}} \odot \boldsymbol{i}_{\mathrm{od}} + \boldsymbol{v}_{\mathrm{oq}} \odot \boldsymbol{i}_{\mathrm{oq}}) \tag{1d}$$

$$\dot{\boldsymbol{Q}} = \omega_{\mathrm{c}}(-\boldsymbol{Q} + \boldsymbol{v}_{\mathrm{oq}} \odot \boldsymbol{i}_{\mathrm{od}} - \boldsymbol{v}_{\mathrm{od}} \odot \boldsymbol{i}_{\mathrm{oq}}) \tag{1e}$$

$$\dot{\boldsymbol{\phi}}_{\mathrm{d}} = \boldsymbol{v}_{\mathrm{od}}^* - \boldsymbol{v}_{\mathrm{od}} \tag{1f}$$

$$\dot{\boldsymbol{\phi}}_{\mathrm{q}} = \boldsymbol{v}_{\mathrm{oq}}^* - \boldsymbol{v}_{\mathrm{oq}} \tag{1g}$$

$$\boldsymbol{i}_{\mathrm{ld}}^* = \boldsymbol{F} \odot \boldsymbol{i}_{\mathrm{od}} - \omega_{\mathrm{n}} \boldsymbol{C}_{\mathrm{f}} \odot \boldsymbol{v}_{\mathrm{oq}} + \boldsymbol{K}_{\mathrm{pv}} \odot (\boldsymbol{v}_{\mathrm{od}}^* - \boldsymbol{v}_{\mathrm{od}}) + \boldsymbol{K}_{\mathrm{iv}} \odot \boldsymbol{\phi}_{\mathrm{d}} \tag{1h}$$

$$\boldsymbol{i}_{\mathrm{lq}}^* = \boldsymbol{F} \odot \boldsymbol{i}_{\mathrm{oq}} + \omega_{\mathrm{n}} \boldsymbol{C}_{\mathrm{f}} \odot \boldsymbol{v}_{\mathrm{od}} + \boldsymbol{K}_{\mathrm{pv}} \odot (\boldsymbol{v}_{\mathrm{oq}}^* - \boldsymbol{v}_{\mathrm{oq}}) + \boldsymbol{K}_{\mathrm{iv}} \odot \boldsymbol{\phi}_{\mathrm{q}} \tag{1i}$$

$$\dot{\boldsymbol{\gamma}}_{\mathrm{d}} = \boldsymbol{i}_{\mathrm{ld}}^* - \boldsymbol{i}_{\mathrm{ld}} \tag{1j}$$

$$\dot{\boldsymbol{\gamma}}_{\mathrm{q}} = \boldsymbol{i}_{\mathrm{lq}}^* - \boldsymbol{i}_{\mathrm{lq}} \tag{1k}$$

$$\boldsymbol{v}_{\mathrm{id}}^* = -\omega_{\mathrm{n}} \boldsymbol{L}_{\mathrm{f}} \odot \boldsymbol{i}_{\mathrm{lq}} + \boldsymbol{K}_{\mathrm{pc}} \odot (\boldsymbol{i}_{\mathrm{ld}}^* - \boldsymbol{i}_{\mathrm{ld}}) + \boldsymbol{K}_{\mathrm{ic}} \odot \boldsymbol{\gamma}_{\mathrm{d}} \tag{1l}$$

$$\boldsymbol{v}_{\mathrm{iq}}^* = \omega_{\mathrm{n}} \boldsymbol{L}_{\mathrm{f}} \odot \boldsymbol{i}_{\mathrm{ld}} + \boldsymbol{K}_{\mathrm{pc}} \odot (\boldsymbol{i}_{\mathrm{lq}}^* - \boldsymbol{i}_{\mathrm{lq}}) + \boldsymbol{K}_{\mathrm{ic}} \odot \boldsymbol{\gamma}_{\mathrm{q}} \tag{1m}$$

$$\dot{\boldsymbol{i}}_{\mathrm{ld}} = -\boldsymbol{r}_{\mathrm{f}} \oslash \boldsymbol{L}_{\mathrm{f}} \odot \boldsymbol{i}_{\mathrm{ld}} + \omega_{\mathrm{n}} \boldsymbol{i}_{\mathrm{lq}} + \boldsymbol{v}_{\mathrm{id}}^* \oslash \boldsymbol{L}_{\mathrm{f}} - \boldsymbol{v}_{\mathrm{od}} \oslash \boldsymbol{L}_{\mathrm{f}} \tag{1n}$$

$$\dot{\boldsymbol{i}}_{\mathrm{lq}} = -\boldsymbol{r}_{\mathrm{f}} \oslash \boldsymbol{L}_{\mathrm{f}} \odot \boldsymbol{i}_{\mathrm{lq}} - \omega_{\mathrm{n}} \boldsymbol{i}_{\mathrm{ld}} + \boldsymbol{v}_{\mathrm{iq}}^* \oslash \boldsymbol{L}_{\mathrm{f}} - \boldsymbol{v}_{\mathrm{oq}} \oslash \boldsymbol{L}_{\mathrm{f}} \tag{1o}$$

$$\dot{\boldsymbol{v}}_{\mathrm{od}} = \omega_{\mathrm{n}} \boldsymbol{v}_{\mathrm{oq}} + \boldsymbol{i}_{\mathrm{ld}} \oslash \boldsymbol{C}_{\mathrm{f}} - \boldsymbol{i}_{\mathrm{od}} \oslash \boldsymbol{C}_{\mathrm{f}} \tag{1p}$$

$$\dot{\boldsymbol{v}}_{\mathrm{oq}} = -\omega_{\mathrm{n}} \boldsymbol{v}_{\mathrm{od}} + \boldsymbol{i}_{\mathrm{lq}} \oslash \boldsymbol{C}_{\mathrm{f}} - \boldsymbol{i}_{\mathrm{oq}} \oslash \boldsymbol{C}_{\mathrm{f}} \tag{1q}$$

$$\dot{\boldsymbol{i}}_{\mathrm{od}} = -\boldsymbol{r}_{\mathrm{c}} \oslash \boldsymbol{L}_{\mathrm{c}} \odot \boldsymbol{i}_{\mathrm{od}} + \omega_{\mathrm{n}} \boldsymbol{i}_{\mathrm{oq}} + \boldsymbol{v}_{\mathrm{od}} \oslash \boldsymbol{L}_{\mathrm{c}} - \boldsymbol{E}_{\mathrm{C}} \boldsymbol{v}_{\mathrm{Bd}} \oslash \boldsymbol{L}_{\mathrm{c}} \tag{1r}$$

$$\dot{\boldsymbol{i}}_{\mathrm{oq}} = -\boldsymbol{r}_{\mathrm{c}} \oslash \boldsymbol{L}_{\mathrm{c}} \odot \boldsymbol{i}_{\mathrm{oq}} - \omega_{\mathrm{n}} \boldsymbol{i}_{\mathrm{od}} + \boldsymbol{v}_{\mathrm{oq}} \oslash \boldsymbol{L}_{\mathrm{c}} - \boldsymbol{E}_{\mathrm{C}} \boldsymbol{v}_{\mathrm{Bq}} \oslash \boldsymbol{L}_{\mathrm{c}} \tag{1s}$$

Eliminating the algebraic variables associated with converters gives

$$\dot{\boldsymbol{\delta}} = \omega^* - \boldsymbol{K}_{\mathrm{p}}(\boldsymbol{P} - (\boldsymbol{P}^* + \boldsymbol{\xi})) + \boldsymbol{u}_{\mathrm{p}} - \omega_{\mathrm{ref}} \tag{2a}$$

$$\dot{\boldsymbol{P}} = \omega_{\mathrm{c}}(-\boldsymbol{P} + \boldsymbol{v}_{\mathrm{od}}\odot\boldsymbol{i}_{\mathrm{od}} + \boldsymbol{v}_{\mathrm{oq}}\odot\boldsymbol{i}_{\mathrm{oq}}) \tag{2b}$$

$$\dot{\boldsymbol{Q}} = \omega_{\mathrm{c}}(-\boldsymbol{Q} + \boldsymbol{v}_{\mathrm{oq}}\odot\boldsymbol{i}_{\mathrm{od}} - \boldsymbol{v}_{\mathrm{od}}\odot\boldsymbol{i}_{\mathrm{oq}}) \tag{2c}$$

$$\dot{\boldsymbol{\phi}}_{\mathrm{d}} = [\cos(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{od}} \tag{2d}$$

$$\dot{\boldsymbol{\phi}}_{\mathrm{q}} = [\sin(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{oq}} \tag{2e}$$

$$\dot{\boldsymbol{\gamma}}_{\mathrm{d}} = \boldsymbol{F}\odot\boldsymbol{i}_{\mathrm{od}} - \omega_{\mathrm{n}}\boldsymbol{C}_{\mathrm{f}}\odot\boldsymbol{v}_{\mathrm{oq}} + \boldsymbol{K}_{\mathrm{pv}}\odot([\cos(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{od}}) + \boldsymbol{K}_{\mathrm{iv}}\odot\boldsymbol{\phi}_{\mathrm{d}} - \boldsymbol{i}_{\mathrm{ld}} \tag{2f}$$

$$\dot{\boldsymbol{\gamma}}_{\mathrm{q}} = \boldsymbol{F}\odot\boldsymbol{i}_{\mathrm{oq}} + \omega_{\mathrm{n}}\boldsymbol{C}_{\mathrm{f}}\odot\boldsymbol{v}_{\mathrm{od}} + \boldsymbol{K}_{\mathrm{pv}}\odot([\sin(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{oq}}) + \boldsymbol{K}_{\mathrm{iv}}\odot\boldsymbol{\phi}_{\mathrm{q}} - \boldsymbol{i}_{\mathrm{lq}} \tag{2g}$$

$$\dot{\boldsymbol{i}}_{\mathrm{ld}} = [-\boldsymbol{r}_{\mathrm{f}}\odot\boldsymbol{i}_{\mathrm{ld}} + \boldsymbol{K}_{\mathrm{pc}}\odot(\boldsymbol{F}\odot\boldsymbol{i}_{\mathrm{od}} - \omega_{\mathrm{n}}\boldsymbol{C}_{\mathrm{f}}\odot\boldsymbol{v}_{\mathrm{oq}} + \boldsymbol{K}_{\mathrm{pv}}\odot([\cos(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{od}}) + \boldsymbol{K}_{\mathrm{iv}}\odot\boldsymbol{\phi}_{\mathrm{d}} - \boldsymbol{i}_{\mathrm{ld}}) + \boldsymbol{K}_{\mathrm{ic}}\odot\boldsymbol{\gamma}_{\mathrm{d}} - \boldsymbol{v}_{\mathrm{od}}]\oslash\boldsymbol{L}_{\mathrm{f}} \tag{2h}$$

$$\dot{\boldsymbol{i}}_{\mathrm{lq}} = [-\boldsymbol{r}_{\mathrm{f}}\odot\boldsymbol{i}_{\mathrm{lq}} + \boldsymbol{K}_{\mathrm{pc}}\odot(\boldsymbol{F}\odot\boldsymbol{i}_{\mathrm{oq}} + \omega_{\mathrm{n}}\boldsymbol{C}_{\mathrm{f}}\odot\boldsymbol{v}_{\mathrm{od}} + \boldsymbol{K}_{\mathrm{pv}}\odot([\sin(\boldsymbol{\delta})\odot(\boldsymbol{U}^* - \boldsymbol{K}_{\mathrm{q}}(\boldsymbol{Q} - \boldsymbol{Q}^*) + \boldsymbol{u}_{\mathrm{q}})] - \boldsymbol{v}_{\mathrm{oq}}) + \boldsymbol{K}_{\mathrm{iv}}\odot\boldsymbol{\phi}_{\mathrm{q}} - \boldsymbol{i}_{\mathrm{lq}}) + \boldsymbol{K}_{\mathrm{ic}}\odot\boldsymbol{\gamma}_{\mathrm{q}} - \boldsymbol{v}_{\mathrm{oq}}]\oslash\boldsymbol{L}_{\mathrm{f}} \tag{2i}$$

$$\dot{\boldsymbol{v}}_{\mathrm{od}} = \omega_{\mathrm{n}}\boldsymbol{v}_{\mathrm{oq}} + \boldsymbol{i}_{\mathrm{ld}}\oslash\boldsymbol{C}_{\mathrm{f}} - \boldsymbol{i}_{\mathrm{od}}\oslash\boldsymbol{C}_{\mathrm{f}} \tag{2j}$$

$$\dot{\boldsymbol{v}}_{\mathrm{oq}} = -\omega_{\mathrm{n}}\boldsymbol{v}_{\mathrm{od}} + \boldsymbol{i}_{\mathrm{lq}}\oslash\boldsymbol{C}_{\mathrm{f}} - \boldsymbol{i}_{\mathrm{oq}}\oslash\boldsymbol{C}_{\mathrm{f}} \tag{2k}$$

$$\dot{\boldsymbol{i}}_{\mathrm{od}} = [-\boldsymbol{r}_{\mathrm{c}}\odot\boldsymbol{i}_{\mathrm{od}} + \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{oq}}\odot\boldsymbol{L}_{\mathrm{c}} + \boldsymbol{v}_{\mathrm{od}} - \boldsymbol{E}_{\mathrm{C}}\boldsymbol{v}_{\mathrm{Bd}}]\oslash\boldsymbol{L}_{\mathrm{c}} \tag{2l}$$

$$\dot{\boldsymbol{i}}_{\mathrm{oq}} = [-\boldsymbol{r}_{\mathrm{c}}\odot\boldsymbol{i}_{\mathrm{oq}} - \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{od}}\odot\boldsymbol{L}_{\mathrm{c}} + \boldsymbol{v}_{\mathrm{oq}} - \boldsymbol{E}_{\mathrm{C}}\boldsymbol{v}_{\mathrm{Bq}}]\oslash\boldsymbol{L}_{\mathrm{c}} \tag{2m}$$

B. Load model

The loads are modelled as constant impedances, thus with the following dynamics:

$$\dot{\boldsymbol{i}}_{\mathrm{Ld}} = -\boldsymbol{r}_{\mathrm{L}}\oslash\boldsymbol{L}_{\mathrm{L}}\odot\boldsymbol{i}_{\mathrm{Ld}} + \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{Lq}} + \boldsymbol{E}_{\mathrm{L}}\boldsymbol{v}_{\mathrm{Bd}}\oslash\boldsymbol{L}_{\mathrm{L}} \tag{3a}$$

$$\dot{\boldsymbol{i}}_{\mathrm{Lq}} = -\boldsymbol{r}_{\mathrm{L}}\oslash\boldsymbol{L}_{\mathrm{L}}\odot\boldsymbol{i}_{\mathrm{Lq}} - \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{Ld}} + \boldsymbol{E}_{\mathrm{L}}\boldsymbol{v}_{\mathrm{Bq}}\oslash\boldsymbol{L}_{\mathrm{L}} \tag{3b}$$

C. Network model

The dynamics of branches are as follows:

$$\dot{\boldsymbol{i}}_{\mathrm{Bd}} = -\boldsymbol{r}_{\mathrm{B}}\oslash\boldsymbol{L}_{\mathrm{B}}\odot\boldsymbol{i}_{\mathrm{Bd}} + \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{Bq}} + \boldsymbol{E}_{\mathrm{B}}\boldsymbol{v}_{\mathrm{Bd}}\oslash\boldsymbol{L}_{\mathrm{B}} \tag{4a}$$

$$\dot{\boldsymbol{i}}_{\mathrm{Bq}} = -\boldsymbol{r}_{\mathrm{B}}\oslash\boldsymbol{L}_{\mathrm{B}}\odot\boldsymbol{i}_{\mathrm{Bq}} - \omega_{\mathrm{n}}\boldsymbol{i}_{\mathrm{Bd}} + \boldsymbol{E}_{\mathrm{B}}\boldsymbol{v}_{\mathrm{Bq}}\oslash\boldsymbol{L}_{\mathrm{B}} \tag{4b}$$

The Kirchhoff's Current Law of each bus yields

$$\boldsymbol{0} = \boldsymbol{E}_{\mathrm{C}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{od}} - \boldsymbol{E}_{\mathrm{L}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{Ld}} - \boldsymbol{E}_{\mathrm{B}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{Bd}} \tag{5a}$$

$$\boldsymbol{0} = \boldsymbol{E}_{\mathrm{C}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{oq}} - \boldsymbol{E}_{\mathrm{L}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{Lq}} - \boldsymbol{E}_{\mathrm{B}}^{\mathrm{T}}\boldsymbol{i}_{\mathrm{Bq}} \tag{5b}$$

D. Full model in ODE form

Now we obtain the full dynamic model of the MG, in DAE form, as follows:

$$\dot{\tilde{\boldsymbol{x}}} = \tilde{f}(\tilde{\boldsymbol{x}}, \boldsymbol{z}) \tag{6a}$$

$$\boldsymbol{0} = \tilde{g}(\tilde{\boldsymbol{x}}) \tag{6b}$$

where (6a) collects (2), (3), and (4); (6b) represents (5); and

$$\tilde{\boldsymbol{x}} = [\boldsymbol{\delta}; \boldsymbol{P}; \boldsymbol{Q}; \boldsymbol{\phi}_{\mathrm{d}}; \boldsymbol{\phi}_{\mathrm{q}}; \boldsymbol{\gamma}_{\mathrm{d}}; \boldsymbol{\gamma}_{\mathrm{q}}; \boldsymbol{i}_{\mathrm{ld}}; \boldsymbol{i}_{\mathrm{lq}}, \boldsymbol{v}_{\mathrm{od}}; \boldsymbol{v}_{\mathrm{oq}}; \boldsymbol{i}_{\mathrm{od}}; \boldsymbol{i}_{\mathrm{oq}}; \boldsymbol{i}_{\mathrm{Ld}}; \boldsymbol{i}_{\mathrm{Lq}}; \boldsymbol{i}_{\mathrm{Bd}}; \boldsymbol{i}_{\mathrm{Bq}}] \tag{7a}$$

$$\boldsymbol{z} = [\boldsymbol{v}_{\mathrm{Bd}}; \boldsymbol{v}_{\mathrm{Bq}}] \tag{7b}$$

Next, we transform the DAE model to a state-space ODE model. First, taking the derivative of both sides of (7b) and dividing (7a) accordingly gives

$$\dot{\tilde{\boldsymbol{x}}}_1 = f_1(\tilde{\boldsymbol{x}}_1, \tilde{\boldsymbol{x}}_2, \boldsymbol{z}) \tag{8a}$$

$$\dot{\tilde{\boldsymbol{x}}}_2 = f_2(\tilde{\boldsymbol{x}}_1, \tilde{\boldsymbol{x}}_2, \boldsymbol{z}) \tag{8b}$$

$$\boldsymbol{0} = \tilde{g}_{\mathrm{der}}(\tilde{\boldsymbol{x}}_2, \boldsymbol{z}) = \boldsymbol{M}_1\tilde{\boldsymbol{x}}_2 + \boldsymbol{M}_2\boldsymbol{z} \tag{8c}$$

where (8a) collects (2a)-(2i); (8b) collects (2j)-(2m), (3), and (4); and

$$\tilde{\boldsymbol{x}}_1 = [\boldsymbol{\delta}; \boldsymbol{P}; \boldsymbol{Q}; \boldsymbol{\phi}_{\mathrm{d}}; \boldsymbol{\phi}_{\mathrm{q}}; \boldsymbol{\gamma}_{\mathrm{d}}; \boldsymbol{\gamma}_{\mathrm{q}}; \boldsymbol{i}_{\mathrm{ld}}; \boldsymbol{i}_{\mathrm{lq}}] \tag{9a}$$

$$\tilde{\boldsymbol{x}}_2 = [\boldsymbol{v}_{\mathrm{od}}; \boldsymbol{v}_{\mathrm{oq}}; \boldsymbol{i}_{\mathrm{od}}; \boldsymbol{i}_{\mathrm{oq}}; \boldsymbol{i}_{\mathrm{Ld}}; \boldsymbol{i}_{\mathrm{Lq}}; \boldsymbol{i}_{\mathrm{Bd}}; \boldsymbol{i}_{\mathrm{Bq}}] \tag{9b}$$

Based on (8c), we have

$$z = -M_2^{-1} M_1 \tilde{x}_2 \tag{10}$$

Substituting this equation into (6a) gives the ODE model as follows:

$$\dot{\tilde{x}} = \tilde{f}(\tilde{x}, -M_2^{-1} M_1 \tilde{x}_2) \tag{11}$$

Finally, we reformulate the ODE model into an affine form in terms of the renewable uncertainty and control, which gives

$$\dot{x} = f(x) + K\xi + g(x)u \tag{12}$$

where $x = \tilde{x}$ is the state variable vector of the ODE model, f and g are functions determined by the MG dynamics, and K being a constant matrix formed by $K_{\mathrm{p},i}$ and zeros.

IV. Parameters of the MG

The parameters of the MG are divided into two categories: time-invariant parameters and time-varying parameters. Time-invariant parameters mainly include the physical parameters of components and partial parameters of controllers. Time-varying parameters include load power, actual and forecast power outputs of generators, and the setpoints of converters.

A. Time-invariant parameters

The values of all time-invariant parameters are listed in Table I and Table II.

TABLE I
Time-invariant parameters of generators

Generator	$r_\mathrm{f}(\Omega)$	L_f(H)	C_f(F)	$r_\mathrm{c}(\Omega)$	L_c(H)	ω_c	K_p	K_q	ω_n(rad/s)	ω^*(rad/s)
G1	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	0.333×10^{-6}	0.333×10^{-5}	100π	100π
G2	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	1.0×10^{-6}	1.0×10^{-5}	100π	100π
G3	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	1.25×10^{-6}	1.25×10^{-5}	100π	100π
G4	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	1.25×10^{-6}	1.25×10^{-5}	100π	100π
G5	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	1.0×10^{-6}	1.0×10^{-5}	100π	100π
G6	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	0.833×10^{-6}	0.833×10^{-5}	100π	100π
G7	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	0.833×10^{-6}	0.833×10^{-5}	100π	100π
G8	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	0.833×10^{-6}	0.833×10^{-5}	100π	100π
G9	0.1	1.35×10^{-3}	5×10^{-5}	0.1	1×10^{-3}	15.705	0.667×10^{-6}	0.667×10^{-5}	100π	100π

Generator	K_pv	K_iv	K_pc	K_ic	F	P_max(MW)	P_min(MW)	Q_max(MVAR)	Q_min(MVAR)
G1	0.05	390	10.5	16×10^3	0.75	3	-3	3	-3
G2	0.05	390	10.5	16×10^3	0.75	1.2	0	2	-2
G3	0.05	390	10.5	16×10^3	0.75	1.2	0	2	-2
G4	0.05	390	10.5	16×10^3	0.75	1.2	0	2	-2
G5	0.05	390	10.5	16×10^3	0.75	1.5	-1.5	2	-2
G6	0.05	390	10.5	16×10^3	0.75	1	-1	1	-1
G7	0.05	390	10.5	16×10^3	0.75	0.8	0	1	-1
G8	0.05	390	10.5	16×10^3	0.75	0.8	0	1	-1
G9	0.05	390	10.5	16×10^3	0.75	1	-1	1	-1

B. Time-varying parameters

Time-varying parameter values of one year at 15-min resolution are generated based on the time-coincident load, wind, and solar data in the ARPA-E PERFORM datasets. The load uncertainties are omitted in our model, and thus time-varying values of r_L and L_L are generated using the actual load data. ARPA-E PERFORM datasets contain forecast and actual data of wind and solar sites, where the forecast data is used to generate time-varying setpoints P^* of wind and solar panel generators, and the deviations between the actual and forecast values are used to generated time-varying errors ξ of wind and solar panel generators. For energy storage systems, their setpoints P^* are set by allocating the unbalanced power (total active load power $-$ total forecast power outputs of wind and solar panel generators) in proportion to the maximal active power outputs. The

TABLE II
PARAMETERS OF LINES

From bus	To bus	$\boldsymbol{r}_{\mathrm{B}}(\Omega)$	$\boldsymbol{L}_{\mathrm{B}}(\mathrm{H})$	From bus	To bus	$\boldsymbol{r}_{\mathrm{B}}(\Omega)$	$\boldsymbol{L}_{\mathrm{B}}(\mathrm{H})$
2	3	0.493	0.000799	2	19	0.164	0.000498
3	4	0.366	0.000593	19	20	1.5042	0.004314
4	5	0.3811	0.000618	20	21	0.4095	0.001523
5	6	0.819	0.00225	21	22	0.7089	0.002984
6	7	0.1872	0.00197	3	23	0.4512	0.000981
7	8	0.7114	0.000748	23	24	0.898	0.002257
8	9	1.03	0.002355	24	25	0.896	0.002232
9	10	1.044	0.002355	6	26	0.203	0.000329
10	11	0.1966	0.000207	26	27	0.2842	0.000461
11	12	0.3744	0.000394	27	28	1.059	0.002972
12	13	1.468	0.003676	28	29	0.8042	0.00223
13	14	0.5416	0.002269	29	30	0.5075	0.000823
14	15	0.591	0.001674	30	31	0.9744	0.003065
15	16	0.7463	0.001735	31	32	0.3105	0.001152
16	17	1.289	0.005478	32	33	0.341	0.001688
17	18	0.732	0.001827				

setpoints $\boldsymbol{U}^*$ and $\boldsymbol{Q}^*$ are obtained by Volt/VAR optimization with the objective of minimizing power losses. The profiles of all time-varying parameters of one year are shown in Fig. 2 to Fig. 5, and Fig. 6 to Fig. 9 show the profiles for one week. The entire one-year data can be found in https://github.com/thanever/SOC/tree/master/33-bus-MG-time-series

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[1] B. Sergi, C. Feng, F. Zhang, B.-M. Hodge, R. Ring-Jarvi, R. Bryce, K. Doubleday, M. Rose, G. Buster, and M. Rossol, “Arpa-e perform datasets,” 2022.

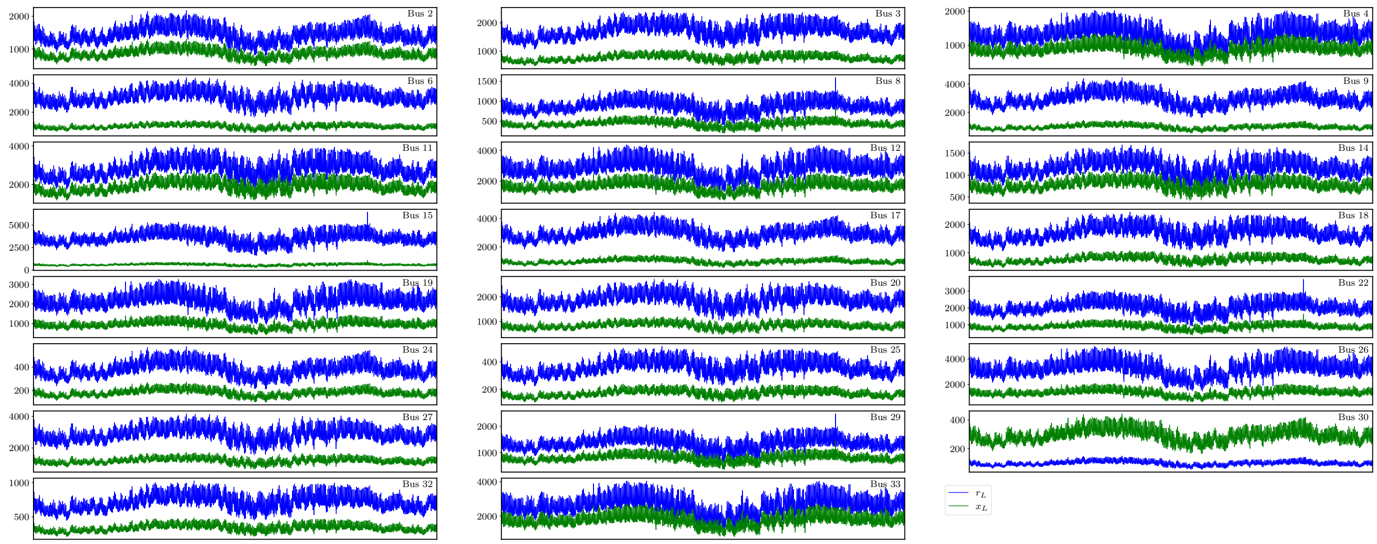

Fig. 2. Profiles of load impedance of one year.

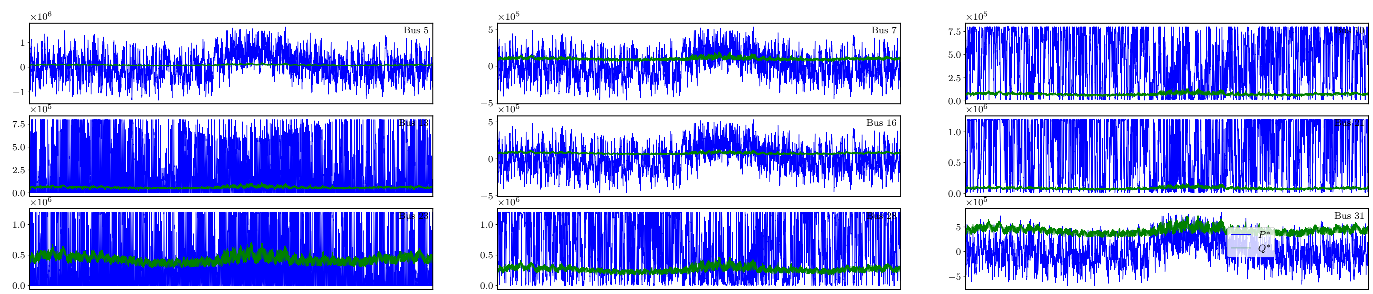

Fig. 3. Profiles of power setpoints of all converters of one year.

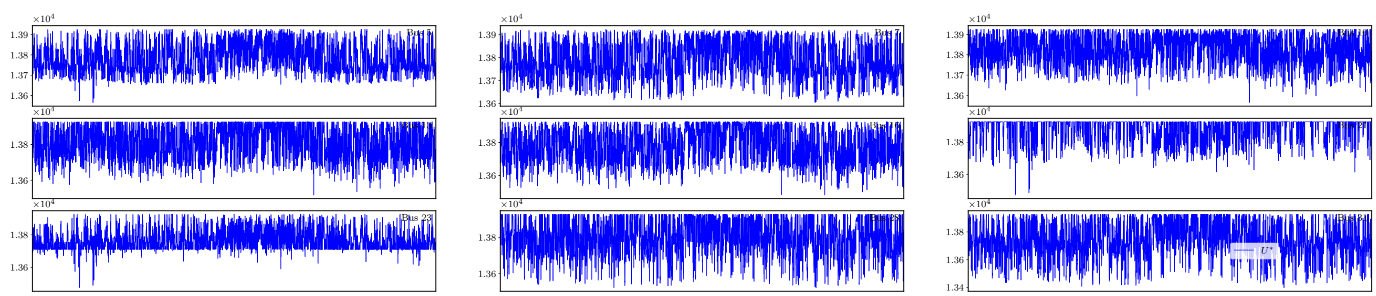

Fig. 4. Profiles of voltage magnitude setpoints of all converters of one year.

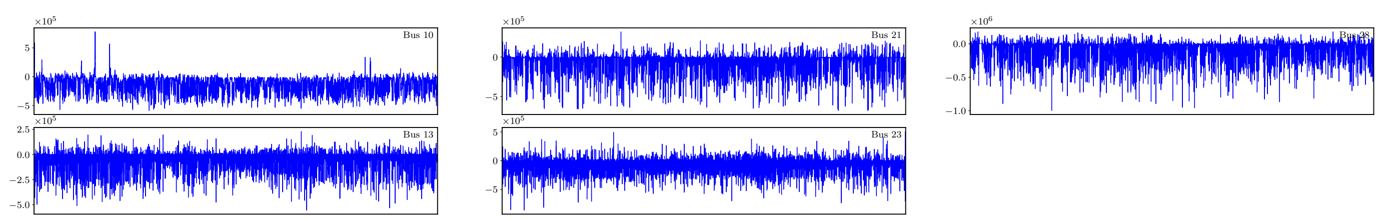

Fig. 5. Profiles of forecast errors of wind and solar panel generators of one year.

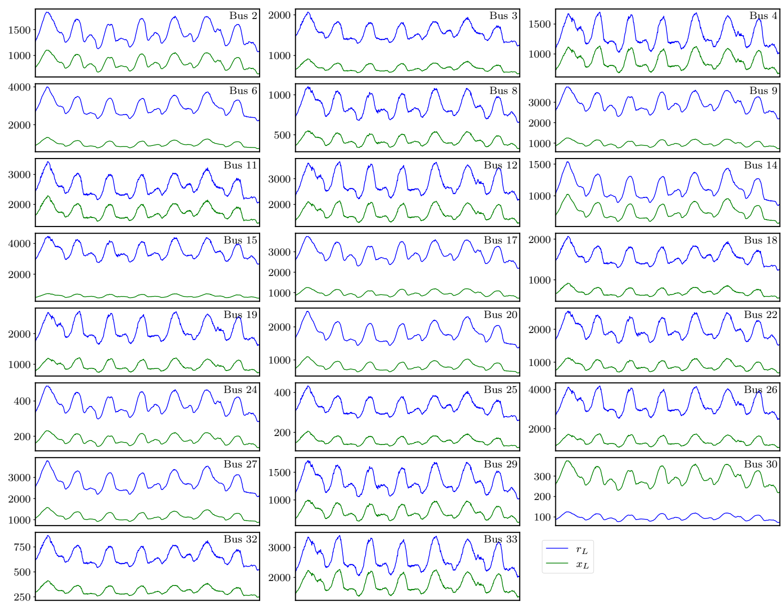

Fig. 6. Profiles of load impedance of one week.

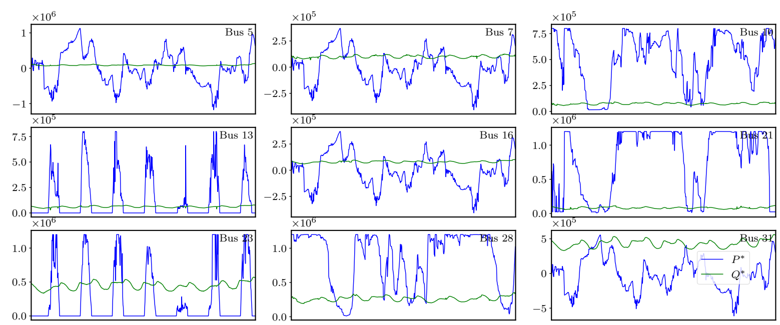

Fig. 7. Profiles of power setpoints of all converters of one week.

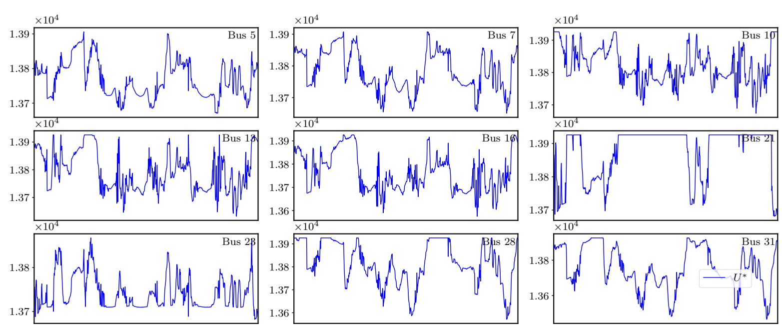

Fig. 8. Profiles of voltage magnitude setpoints of all converters of one week.

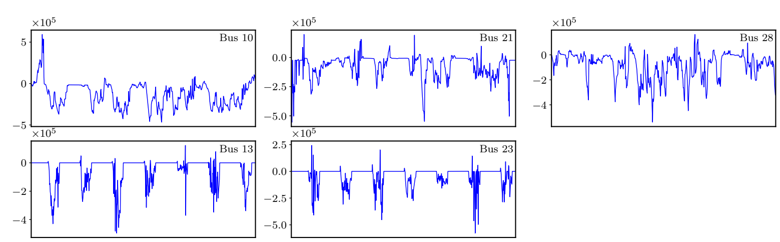

Fig. 9. Profiles of forecast errors of wind and solar panel generators of one week.