Research on security boundary of active power distribution system with distributed energy storage

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Introduction

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Research field: Security of active distribution network

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CONTENTS

1 Introduction

2 Research content

3 Simulation results

4 Conclusion

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1 Introduction

Distribution network security area / boundary

- The rapid assessment of distribution network security
- Observe the current state of the power grid intuitively
- Take corrective measures in advance

1. Two-way power flow characteristics
2. Multi-space-time coupling
3. High power electronization

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2 Research content

Security boundary mathematical model of traditional distribution network

$$\Omega_{\mathrm{DSSR}}=\left\{W_{\mathrm{f}}\left|\begin{array}{l}F_{\mathrm{i}}+\sum\limits_{\mathrm{F_j}\in\mathrm{BF(i)},\mathrm{j}\neq\mathrm{i}}F_{\mathrm{j}}\leq C_{\mathrm{BF(i)}}\\ F_{\mathrm{i}}+\sum\limits_{\mathrm{F_j}\in\mathrm{BT(i)},\mathrm{j}\neq\mathrm{i}}F_{\mathrm{j}}+\sum\limits_{\mathrm{F_k}\in\mathrm{T_i},\mathrm{k}\neq\mathrm{i}}F_{\mathrm{k}}\leq C_{\mathrm{BT(i)}}\\ (\forall \mathrm{i}=1,2,\ldots,\mathrm{n})\end{array}\right.\right\}$$

Security boundary mathematical model considering distributed energy storage

$$\Omega_{\mathrm{TQSR}}=\left\{W_{\mathrm{p}}\left|\begin{array}{l}\mathrm{st.A}\left\{\begin{array}{l}P_{\mathrm{L,i}}^{\min}\le P_{\mathrm{L,i}}\le P_{\mathrm{L,i}}^{\max}\\ -P_{\mathrm{M,i}}^{\min}\le P_{\mathrm{M,i}}\le 0\end{array}\right.\\ \mathrm{st.B}\left\{\begin{array}{l}|P_{\mathrm{B,i}}|=|\sum\limits_{\mathrm{j}\in\wedge\mathrm{B,i}}P_{\mathrm{j}}|\le C_{\mathrm{B,i}},\forall i\in\mathrm{B}\\ |P_{\mathrm{T,i}}|=|\sum\limits_{\mathrm{j}\in\wedge\mathrm{T,i}}P_{\mathrm{j}}|\le C_{\mathrm{T,i}},\forall i\in\mathrm{T}\end{array}\right.\\ \mathrm{st.C}\left\{\begin{array}{l}|P_{\mathrm{B,i(k)}}|=|\sum\limits_{\mathrm{j}\in\wedge\mathrm{B,i(k)}}P_{\mathrm{j}}|\le C_{\mathrm{B,i}},\\ (\forall i\in\mathrm{B},\ \varphi_{\mathrm{k}}\notin\mathrm{B})\\ |P_{\mathrm{T,i(k)}}|=|\sum\limits_{\mathrm{j}\in\wedge\mathrm{T,i(k)}}P_{\mathrm{j}}|\le C_{\mathrm{T,i}},\\ (\forall i\in\mathrm{T},\ \varphi_{\mathrm{k}}\notin\mathrm{T})\end{array}\right.\\ (\forall \mathrm{i}=1,2,...,\mathrm{n})\end{array}\right.\right\}$$

Based on the mathematical model of security boundary of traditional power distribution system, the influence of distributed energy storage on the security of power distribution system is considered.

Comparison and analysis of boundary equations

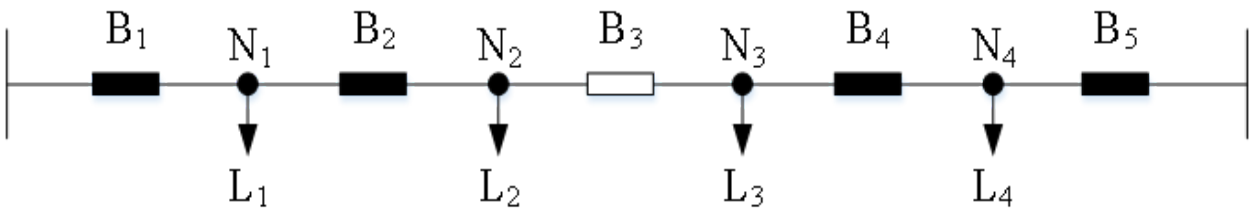

Fig. 1. Example of traditional distribution network

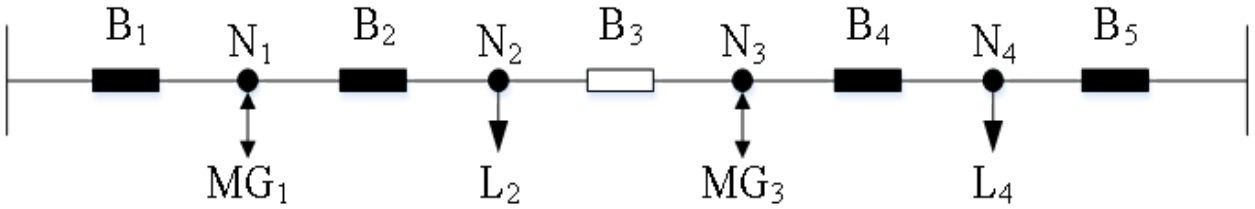

Fig. 2. Example of active distribution network with energy storage

Basic parameters	Traditional distribution network	Active distribution network
Line capacity/MVA	1	1
Load power range/MVA	[0,0.8]	[0,1.5]
MG output range/MVA	-	[-0.4,0.2]

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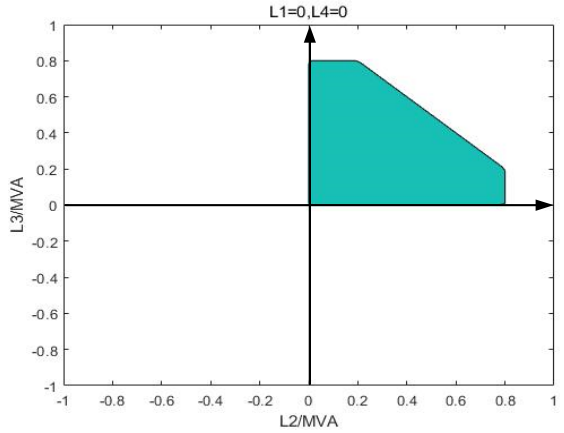
The security boundary equation of the examples

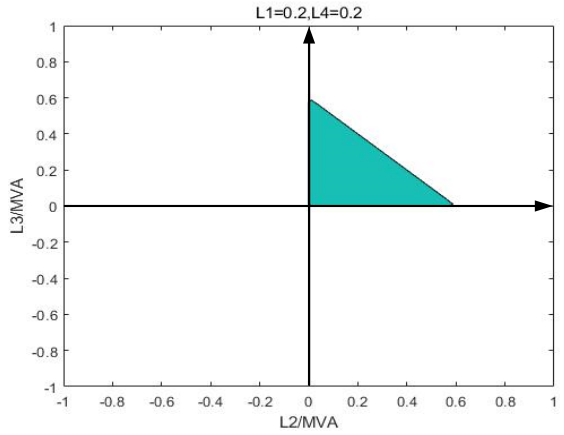
Scenario	Line	Traditional distribution network	Active distribution network
Normal operation constraint	B_1	$P_{L1}+P_{L2}=1$	$\lvert P_{M1}+P_{L2}\rvert=1$
	B_2	$P_{L2}=1$	$P_{L2}=1$
	B_4	$P_{L3}=1$	$\lvert P_{M3}\rvert=1$
	B_5	$P_{L3}+P_{L4}=1$	$\lvert P_{M3}+P_{L4}\rvert=1$
N-1constraint (B_1 fault)	B_2	$P_{L1}=1$	$\lvert P_{M1}\rvert=1$
	B_3	$P_{L2}+P_{L1}=1$	$\lvert P_{L2}+P_{M1}\rvert=1$
	B_4	$P_{L3}+P_{L2}+P_{L1}=1$	$\lvert P_{M3}+P_{L2}+P_{M1}\rvert=1$
	B_5	$P_{L4}+P_{L3}+P_{L2}+P_{L1}=1$	$\lvert P_{L4}+P_{M3}+P_{L2}+P_{M1}\rvert=1$
N-1constraint (B_5 fault)	B_1	$P_{L1}+P_{L2}+P_{L3}+P_{L4}=1$	$\lvert P_{M1}+P_{L2}+P_{M3}+P_{L4}\rvert=1$
	B_2	$P_{L2}+P_{L3}+P_{L4}=1$	$\lvert P_{L2}+P_{M3}+P_{L4}\rvert=1$
	B_3	$P_{L3}+P_{L4}=1$	$\lvert P_{M3}+P_{L4}\rvert=1$
	B_4	$P_{L4}=1$	$P_{L4}=1$

3 Simulation results

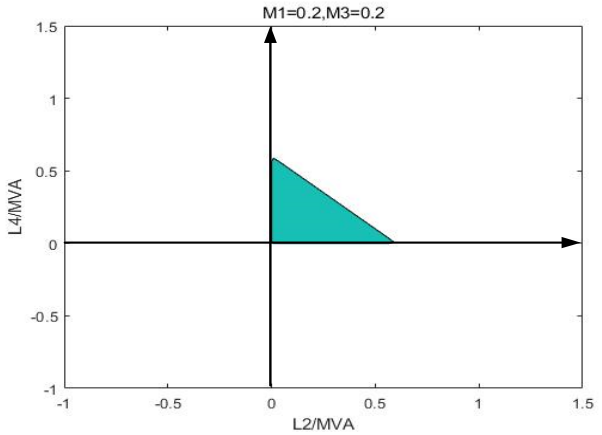
Comparison of 2D observation results

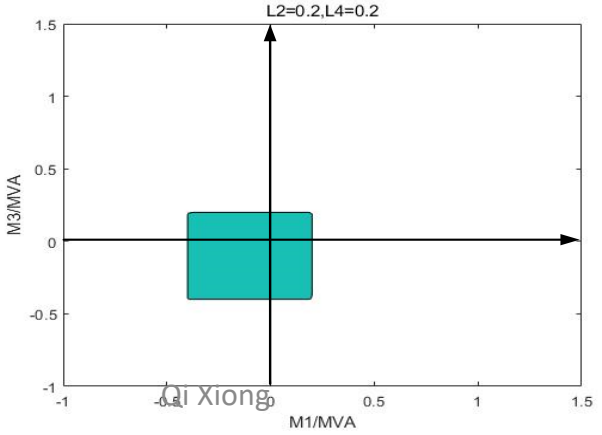
Traditional distribution network

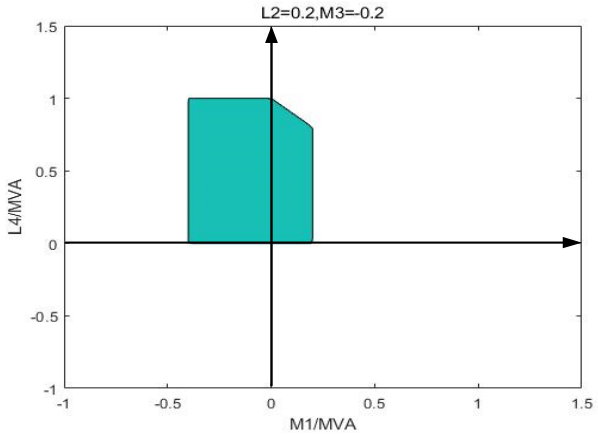


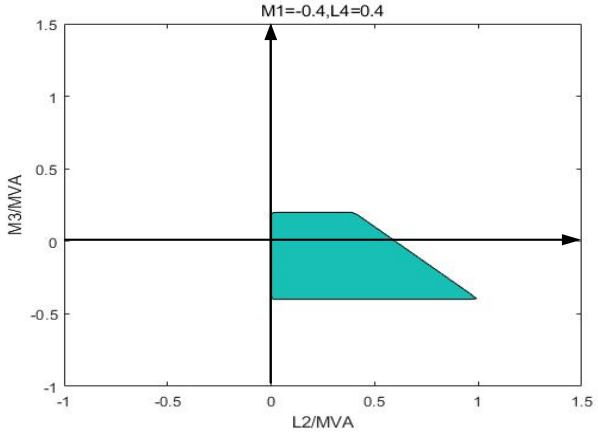


Active distribution network







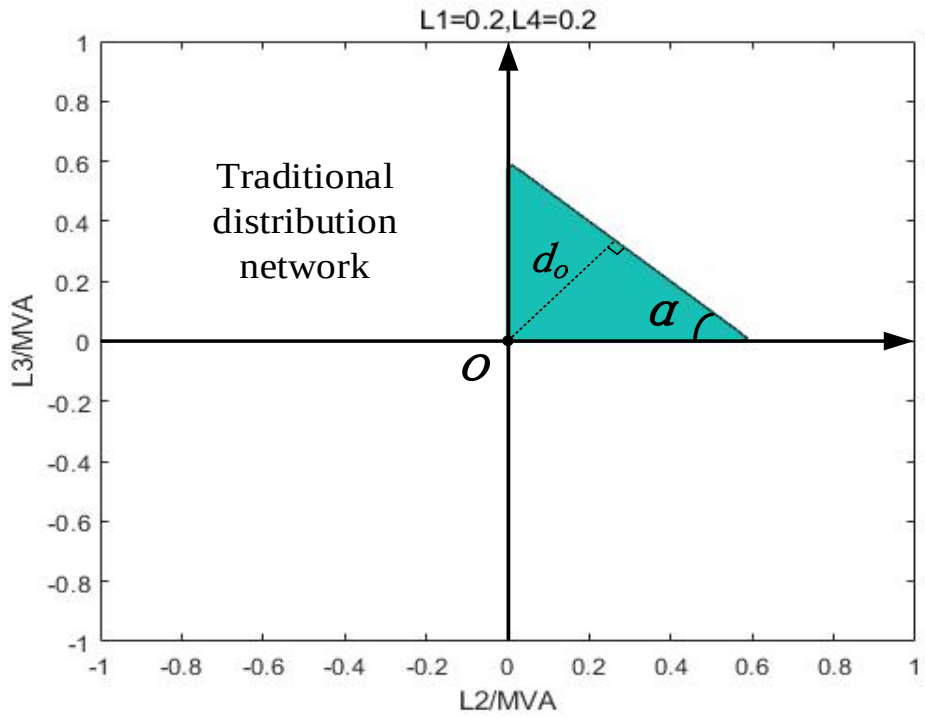


Topological quadrant features of 2D images

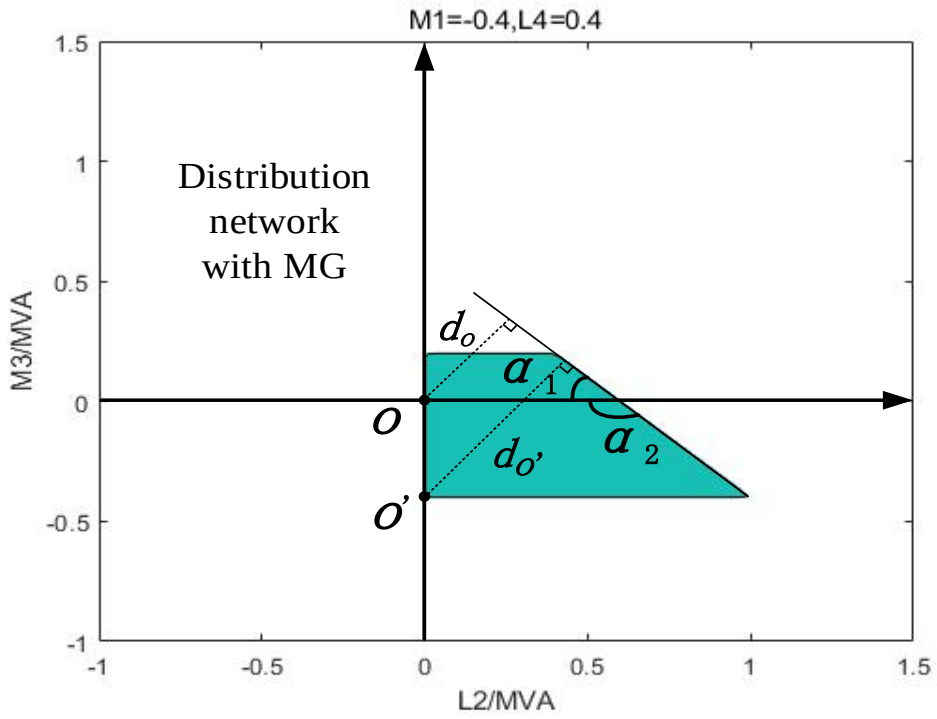
Distribution network type	The X-axis observation node type	The Y-axis observation node type	Quadrant of the Image
Traditional distribution network	Load (outflow)	Load (outflow)	Quadrant I
Active distribution network	Load (outflow)	Load (outflow)	Quadrant I
	MG (in or out)	Load (outflow)	Quadrant I+II
	MG (in or out)	MG (in or out)	All quadrants
	Load (outflow)	MG (in or out)	Quadrant I+IV

Comparison of 2D observation results

Traditional distribution network



Active distribution network



4 Conclusion

4 Conclusion

- This article **proposes a method** to solve the security boundary of **active power distribution system** of distributed energy storage access.
- A reasonable **mathematical model and relevant constraints** are established, which **provides a theoretical basis** for future power distribution system security assessment and planning.
- **The feasibility and effectiveness** of the method are verified by example simulation.
- **The influence of distributed energy storage** on the security of distribution system is analyzed.

THANKS FOR EVERYONE