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Reliability Analysis of Microgrid

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3. Background

- Microgrid is a local energy system that contains loads, distributed generation and energy storage.
- Microgrid is flexible in the operation mode: it can operate either in grid-connected or islanded mode. It has a potential of improving reliability of local power supply.
- Microgrid has become an important component of distribution system. In the development of microgrid, its security and reliability analysis becomes an important issue in order to ensure reliable power supply.
- Reliability evaluation of microgrid has been recognized as one of the major challenges in the development of microgrid.

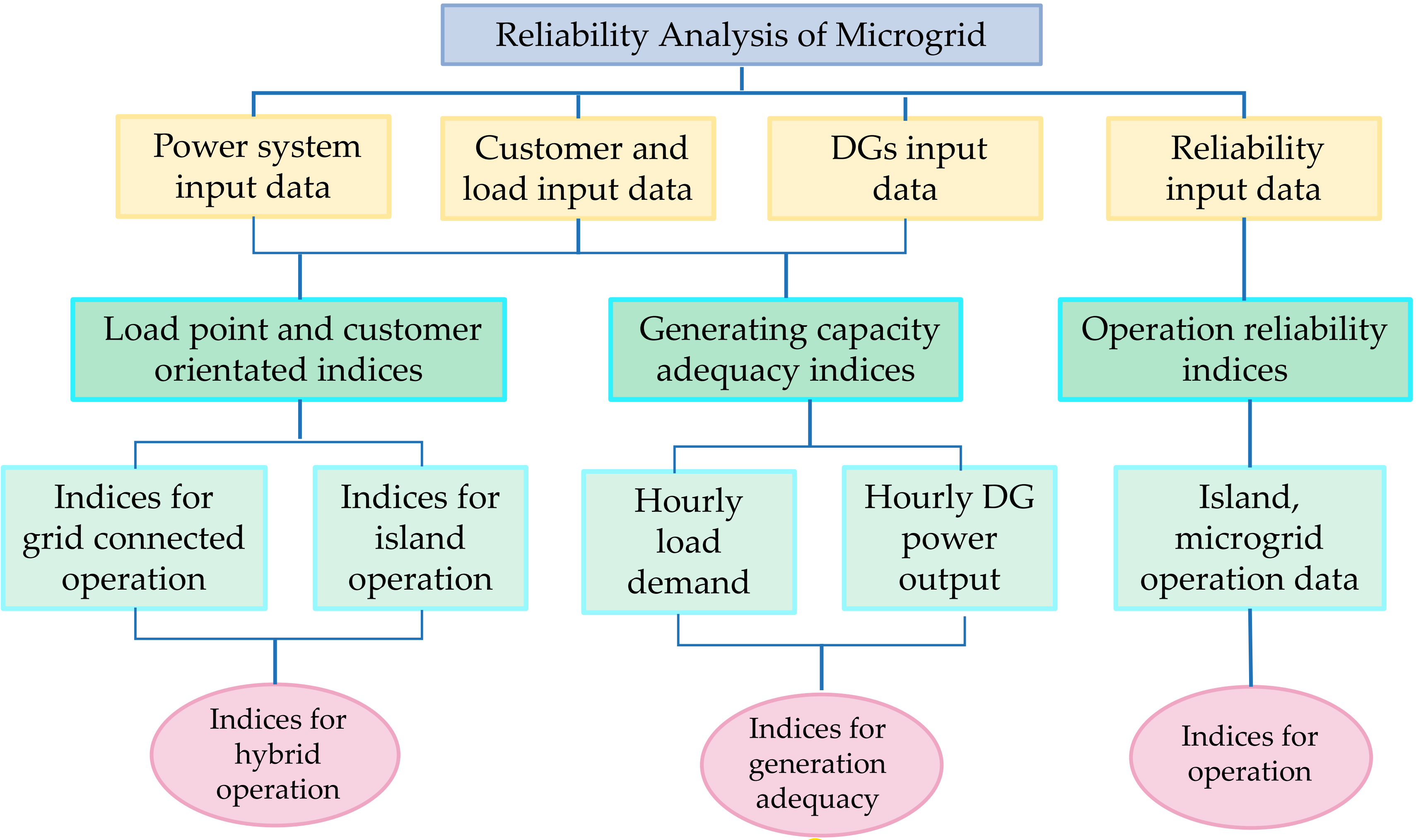
4. Purpose

- Provide an applicable method for reliability analysis of microgrid, which can be used to evaluate reliability of practical microgrid and is able to deal with uncertainty and significant failure modes of the microgrid.
- The method will incorporate local power output characteristics of intermittency and randomness of renewable energy and the flexible operation modes of microgrid so that their influences on the reliability are included in the reliability assessment.

5. Literature study: focus

- Microgrid structure and operation modes
- Reliability evaluation method categories
- Reliability indices used for microgrid
- Wind power output modelling
- Solar power output modelling
- Energy storage system reliability modelling

6. Overview of method



7. Load point and customer orientated reliability indices

Load point indices:

$$\lambda_{lp} = \sum_i \lambda_i$$

$$U_{lp} = \sum_i \lambda_i \cdot r_i$$

$$r_{lp} = \frac{U_{lp}}{\lambda_{lp}}$$

System indices:

$$SAIFI = \frac{\sum \lambda_i \cdot N_i}{\sum N_i}$$

$$SAIDI = \frac{\sum U_i \cdot N_i}{\sum N_i}$$

$$AENS = \frac{\sum L_{a(i)} \cdot U_i}{\sum N_i}$$

$$ASAI = \frac{\sum N_i \cdot 8760 - \sum U_i \cdot N_i}{\sum N_i \cdot 8760}$$

8. Evaluate Load point and customer orientated reliability indices

Grid connected mode

$$\lambda_{lp\_g} = \sum_i \lambda_i + \lambda_{up}$$

$$U_{lp\_g} = \sum_i \lambda_i \cdot r_i + U_{up}$$

$$r_{lp\_g} = \frac{U_{lp\_g}}{\lambda_{lp\_g}}$$

Island mode:

$$\lambda_{lp\_is} = \sum_i \lambda_i + P\lambda_{up} + (1-P)\sum_j \frac{\lambda_{DGj}\lambda_{up}(T_{DGj} + r_{up})}{1 + \lambda_{DGj} \cdot T_{DGj} + \lambda_{up} \cdot r_{up}}$$

$$r_{lp\_is} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} + P\frac{\lambda_{up} r_{up}}{\lambda_{up}} + (1-P)\sum_j \frac{T_{DGj} r_{up}}{T_{DGj} + r_{up}}$$

$$U_{lp\_is} = \lambda_{lp\_is} r_{lp\_is}$$

9. Evaluate Load point and customer orientated reliability indices

Microgrid (hybrid) operation mode

$$\lambda_{lp\_h} = \lambda_{lp\_g} P_g + \lambda_{lp\_is} (1 - P_g)$$

$$U_{lp\_h} = U_{lp\_g} P_g + U_{lp\_is} (1 - P_g)$$

$$r_{lp\_h} = \frac{U_{lp\_h}}{\lambda_{lp\_h}}$$

10. Generating capacity adequacy reliability indices

- Loss Of Load Expectation (LOLE): the number of hours in a year during which the daily peak load surpasses the accessible generating capacity.
- Loss Of Energy Expectation (LOEE): energy expected not to supply in a year by generation unavailability, also known as expected energy not supplied.

$$LOLE = \sum_{k=1}^{n} P_k \cdot t_k \quad (h/yt)$$

$$LOEE = \sum_{i=1}^{n} C_k \cdot P_i \cdot 8760 \quad (kWh/yr)$$

$$LOLP = \frac{LOLE\ (hours/yr)}{8760\ (hours)}$$

11. Operation reliability indices in islanded mode

- Island Operation Successful Rate (IOSR): the probability of a microgrid to switch successfully from grid-connected mode to islanded mode.
- Microgrid Islanded Operation Probability (MIOP): the fraction of time that microgrid is operated in islanded mode.

$$IOSR = \frac{Total\ number\ of\ forming\ island\ successfully}{Total\ number\ of\ outages\ on\ PCC}$$

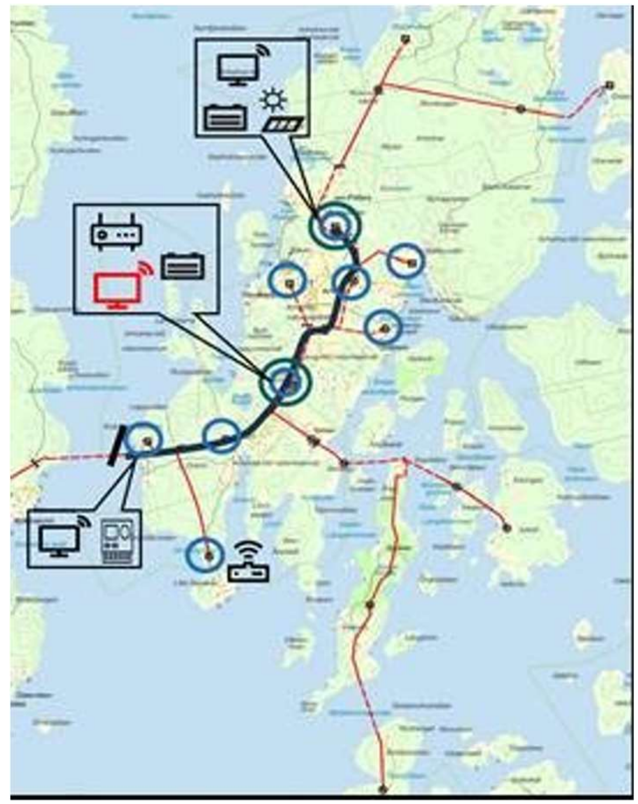
$$MIOP = \frac{Microgrid\ hours\ in\ islanded\ mode}{Total\ microgrid\ operation\ hours}$$

12. Case study

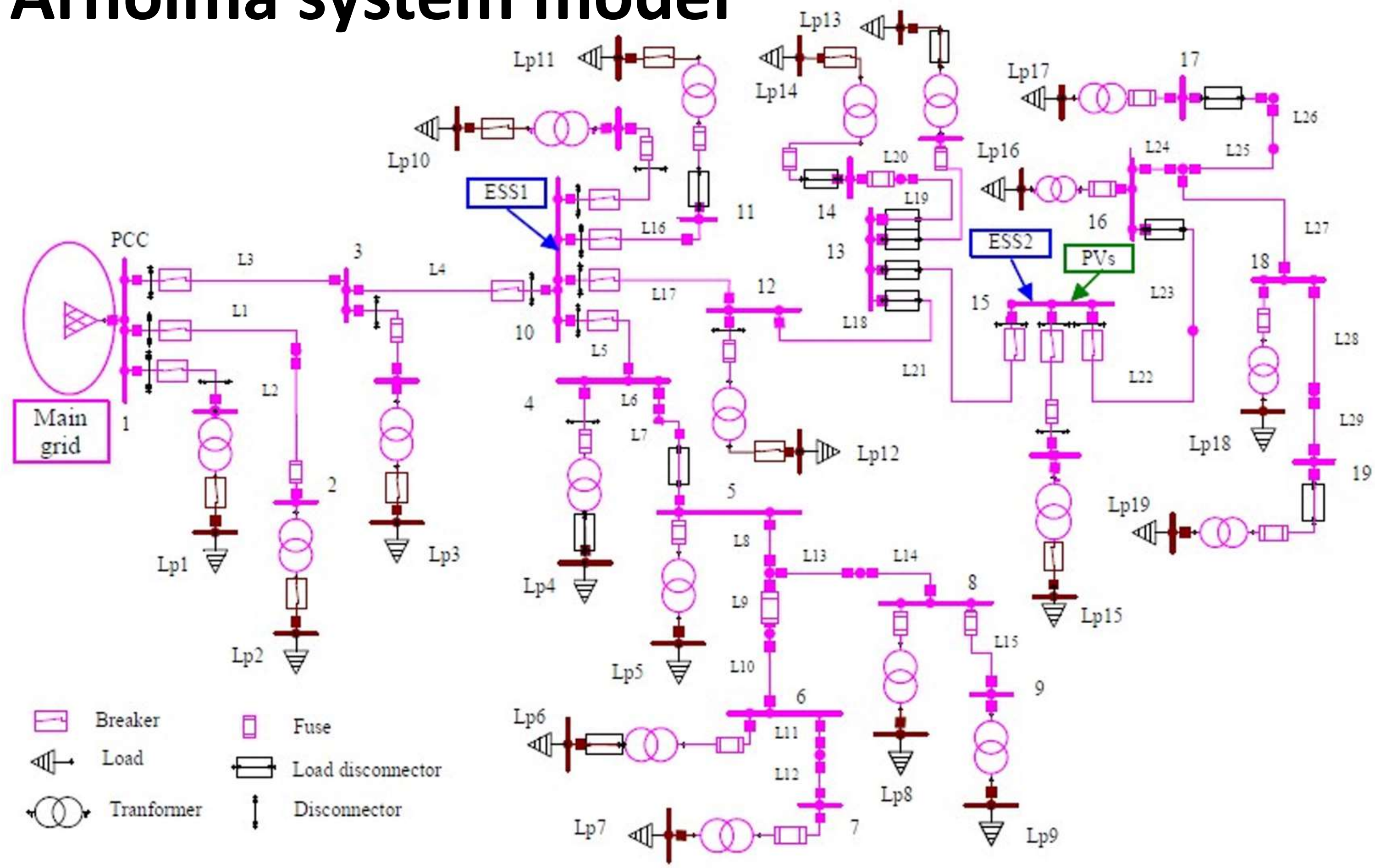
Apply the method developed on a real Vattenfall microgrid Arholma to show reliability evaluation process.

Island operable microgrid pilot Arholma

- Connected to main grid via point of common coupling
- 2 x energy storage systems
- 1 solar photovoltaic
- MV & LV protection
- Microgrid controller, communivation



13. Arholma system model

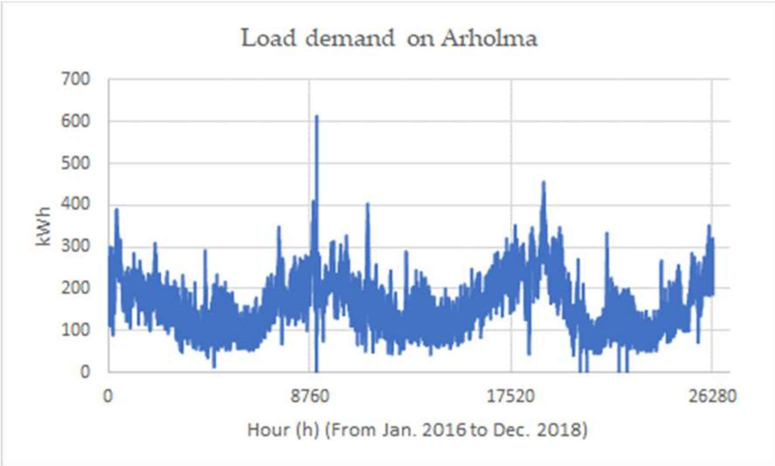


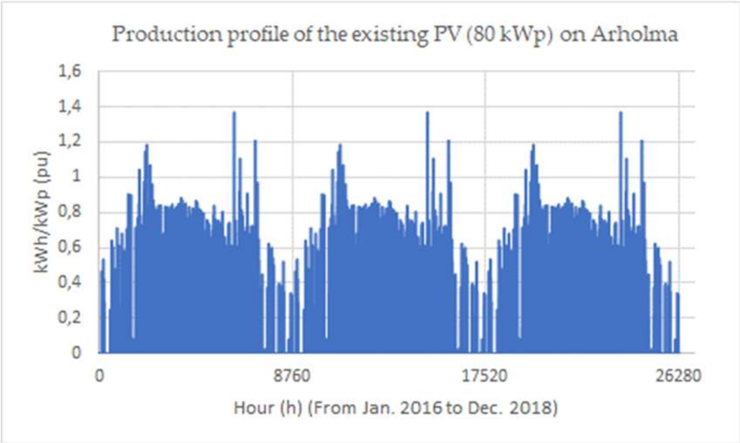
14. Input data: system data, customer and load data. DG data

Line number	Type	Length (km)	Line number	Type	Length (km)
L1	UC	0,214	L16	UC	0,863
L2	OL	0,813	L17	UC	0,796
…	…	…	…	…	…

Load Point	Number of customers	Load (kW)
Load Point 1	4	6,14
Load Point 2	11	2,21
…	…	…

Nummer of PV modules	6 connected in series
Maximum PV power (kWp)	2,73
Type of PV module	Longi Solar Hi-MO 4m LR4-72HPH 450
ESS maximum apparent power (kVA)	2x200
ESS available active power (kW) (at PF = 0,8)	2x160
ESS installed energy (kWh)	2x336





15. Input data, Reliability data

Item	Failure rate ? (failure/year)	Repair time r (hour/failure)	P
Isolation operation			0,5%
ESS1, ESS2	1,1	5	
PV	0,9	5	

Component / Item	Failure rate ? (failure/year.km), (failure/year.unit)	Repair time r (Downtime) (hour/failure)	Unavailability U	Availability A	References / Sources
PCC	2,100	2,000	0,04795%	99,9521%	Estimated based on [42- 45, 47]
Power transformer 11/0,4 kV	0,012	10,000	0,0014%	99,9986%	Estimated based on [46]
Disconnector 11 kV	0,008	4,0	0,00037%	99,99963%	Estimated based on Vattenfall statistics
Load disconnector 11 kV	0,008	4,0	0,00037%	99,99963%	Estimated based on Vattenfall statistics
Load disconnector 0,4 kV	0,010	4,0	0,00046%	99,99954%	Estimated based on Vattenfall statistics
Circuit breaker 11 kV	0,011	4,0	0,00050%	99,99950%	Estimated based on [46]
Circuit breaker 0,4 kV	0,014	4,0	0,00064%	99,99936%	Estimated based on [46]
Underground cable 11 kV	0,0200	5,0	0,00114%	99,99886%	Estimated based on [46]
Hanging cable 11 kV	0,0400	6,0	0,00274%	99,99726%	Estimated based on [46]
Overhead line 11 kV	0,1200	20,0	0,02740%	99,97260%	Estimated based on [46]

16. Load point and customer orientated reliability indices

	Grid concected mode	Islanded mode	Hybrit mode
SAIFI (f/yr.cust)	2,263	1,612	2,003
SAIDI (h/yr.cust)	5,249	2,888	4,304
AENS (kWh/yr.cust)	4,617	2,788	3,886
ASAI	99,9401%	99,9670%	99,9509%

Load point	Failure rate ?_h (f/yr)	Repair time r_h (h/f)	Unavailability U_h (h/yr)
Load point 1	1,946	1,940	3,775
Load point 2	2,040	2,802	5,716
Load point 3	1,933	1,928	3,726
Load point 4	1,984	1,998	3,964
Load point 5	1,985	2,011	3,992
Load point 6	2,037	2,101	4,280
Load point 7	2,073	2,175	4,508
Load point 8	1,985	2,011	3,992
Load point 9	2,004	2,048	4,105
Load point 10	1,959	1,956	3,832
Load point 11	1,976	1,983	3,918
Load point 12	1,994	2,007	4,002
Load point 13	1,987	1,997	3,968
Load point 14	2,013	2,036	4,099
Load point 15	2,019	2,031	4,100
Load point 16	2,278	3,998	9,105
Load point 17	2,278	3,998	9,105
Load point 18	2,278	3,998	9,105
Load point 19	2,286	3,998	9,137

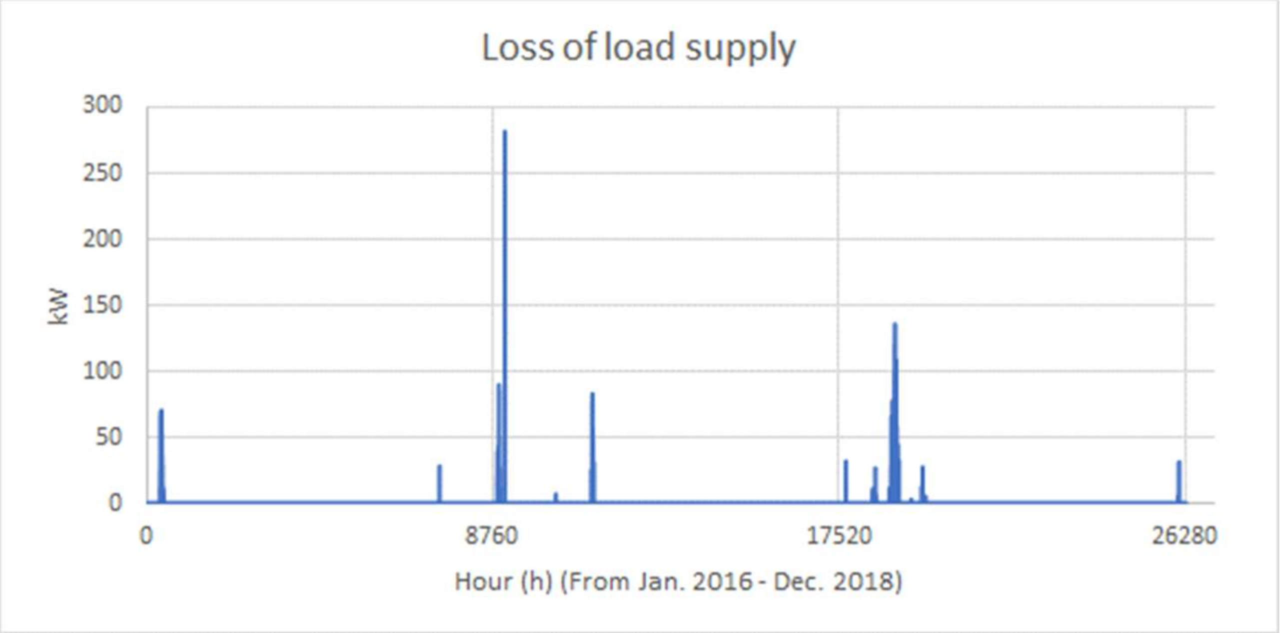
17. Generating capacity adequacy indices

LOLE(h/yr)	LOEE(kWh/yr)	LOLP
130	4613	1,5%

$$LOLE = \frac{\sum_{i=1}^{n(R)} t(R)_i}{N}$$

$$LOEE = \sum_{i=1}^{n(R)} t(R)_i \cdot Lc(R)_i$$

$$LOLP = \frac{LOLE\ (hours/yr)}{8760\ (hours)}$$



18. Conclusion

The project proposes a method for practical reliability analysis of microgrid. The method is able to deal with uncertainty and significant failure modes of a microgrid and can be used as an applicable method for microgrid reliability evaluation.

The method incorporates power output characteristics of intermittency and randomness of local renewable energy sources as well as the flexible operation modes of microgrid so that their influence on the reliability are included in the reliability assessment.

Thank you for your attention!