# Optimal Power Flow for Microgrids with Faulty Generators

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POSTECH Electrical Engineering

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# Microgrids and its operation

## Real-world examples of microgrids



| Stone Edge Farms Microgrid | | | |
|---|---|---|---|
| | | | |
| *Energy Storage* | *Total Capacity* | *Units* | *Individual Capacity* |
| Tesla Lithium Cobalt | 250kW \| 475 kWh | 5 | 50kW \| 95kWh |
| Sony LiFePo | 2.4kW \| 9.6 kWh | 8 | 300W \| 1.2 kWh |
| SimpliPhi Power LiFePo | 23.8kW \| 45 kWh | 7 | 3.4kW \| 6.4 kWh |
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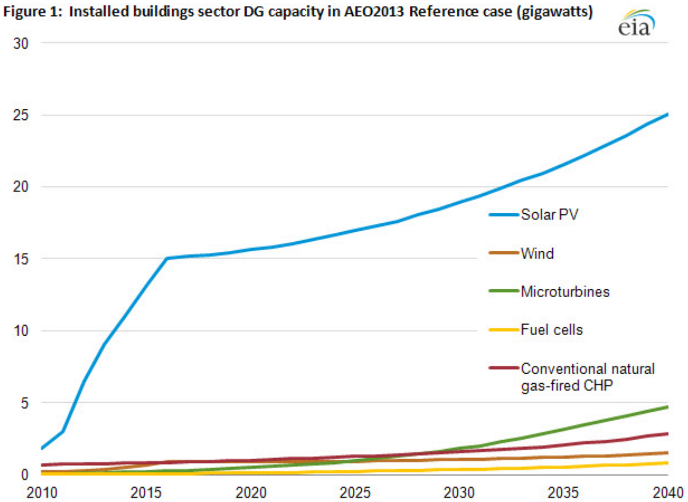


Source: US energy information administration
Reported in the Annual Energy Outlook 2013

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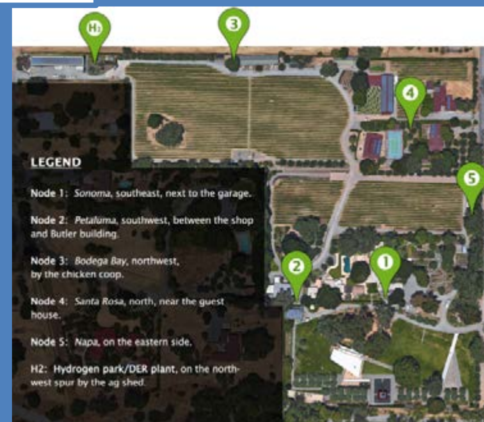


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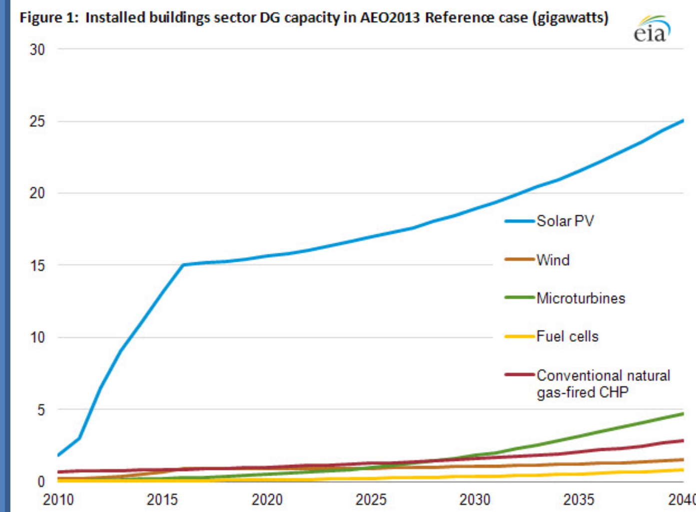


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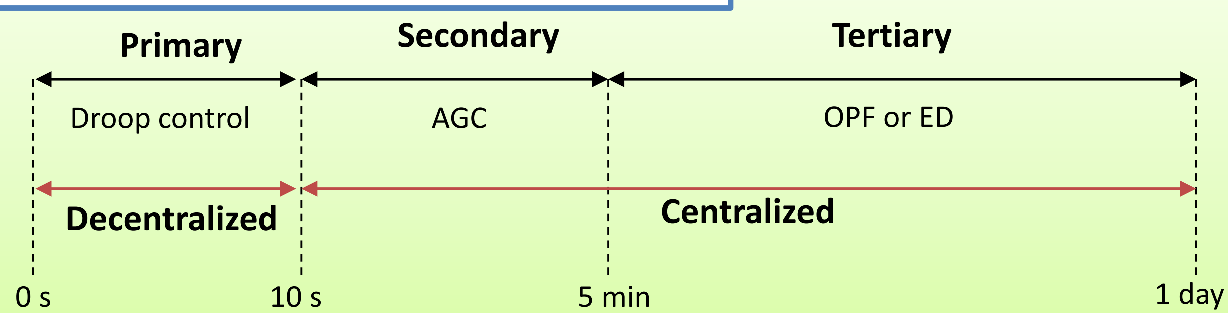
## Hierarchical operation of microgrids



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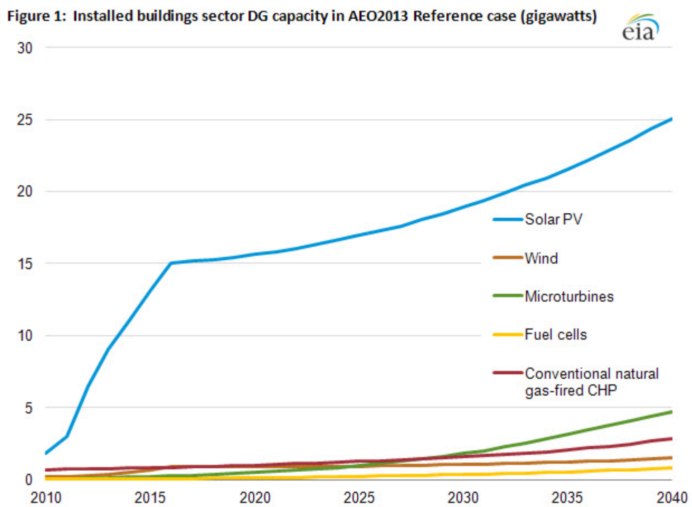



Source: US energy information administration
Reported in the Annual Energy Outlook 2013

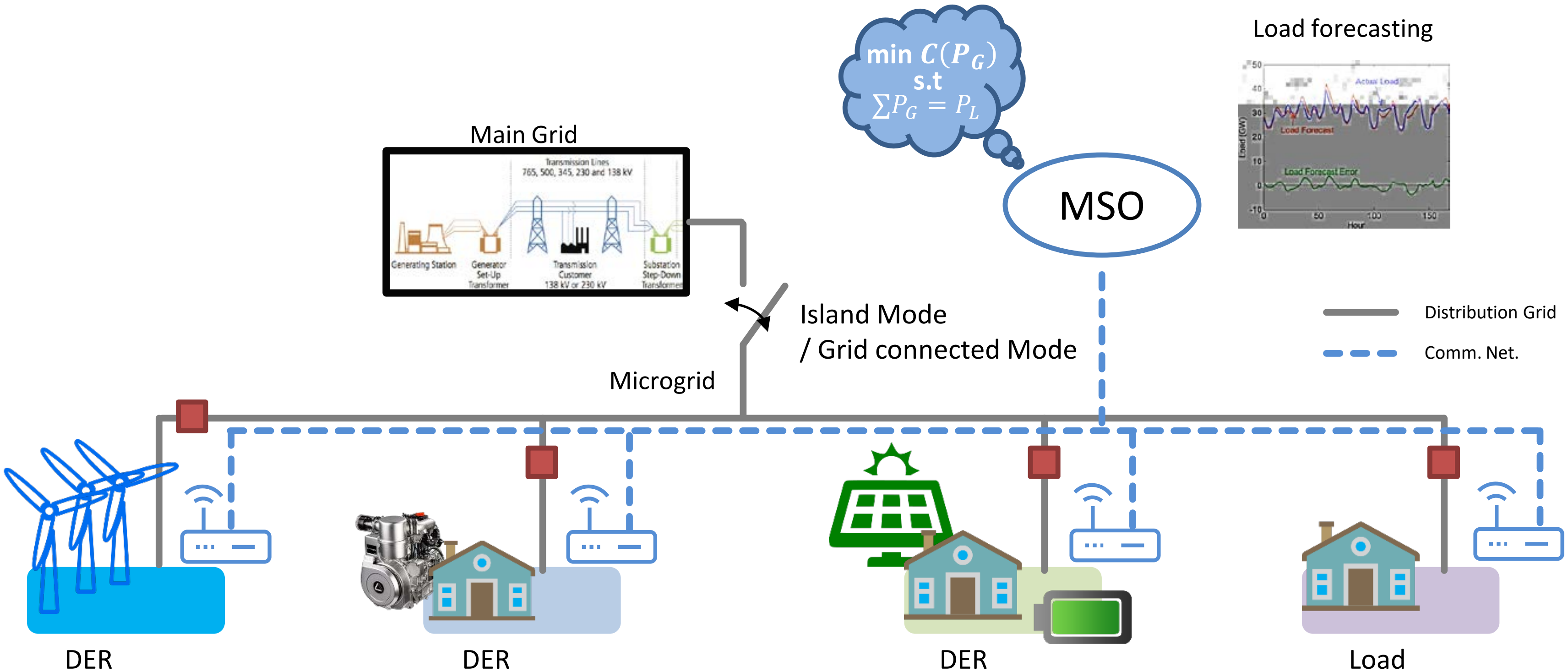
## Hierarchical operation of microgrids

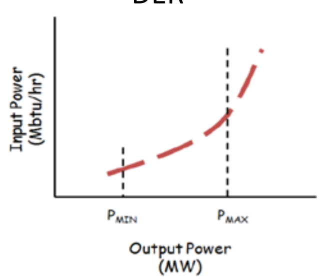
| Primary | Secondary | Tertiary |
|---|---|---|
| Droop control | AGC | OPF or ED |
| Decentralized | Centralized | |

**Stability of a grid** — **Economic aspect of the operation**

0 s — 10 s — 5 min — 1 day

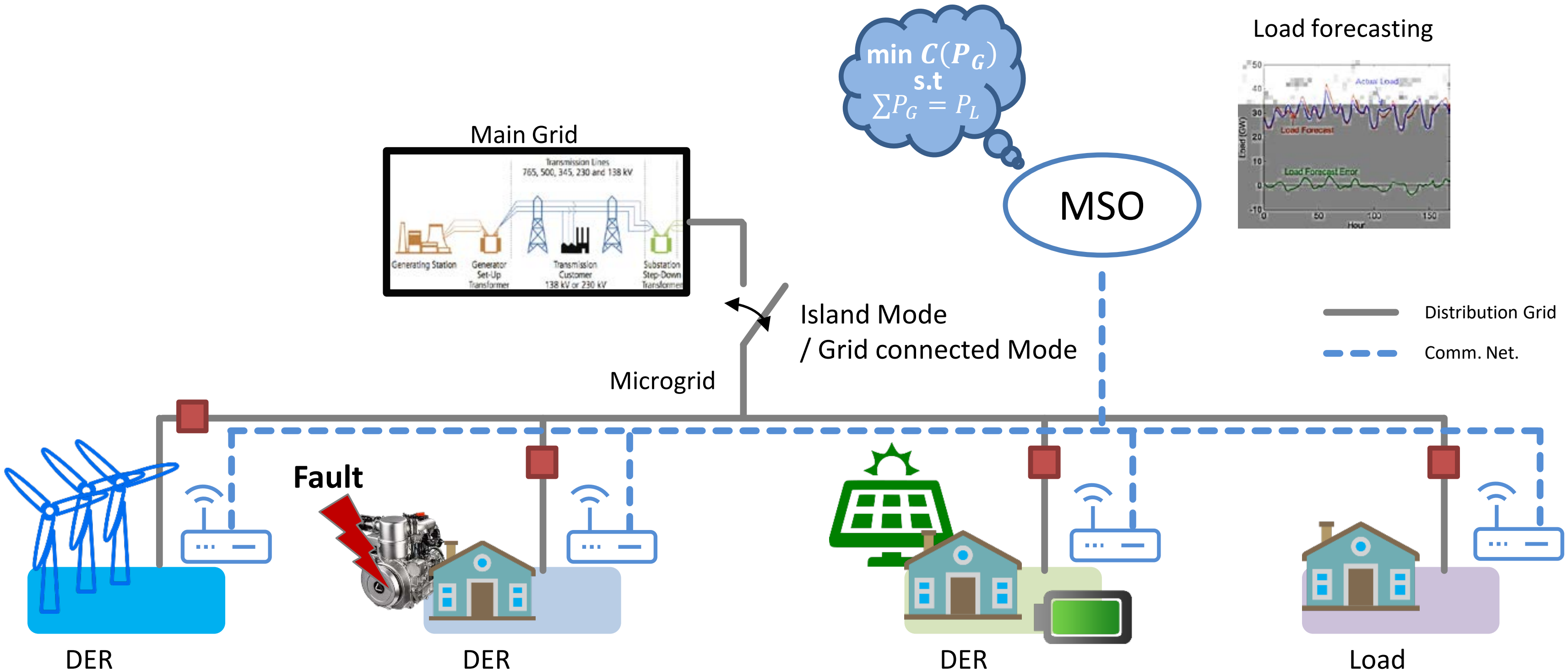
# Operation of Microgrids

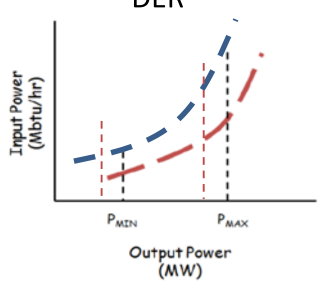



MSO is assumed to know I/O curve of generation units

# Operation of Microgrids

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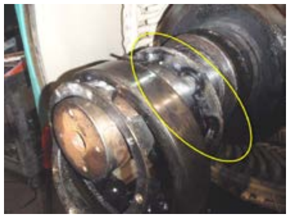
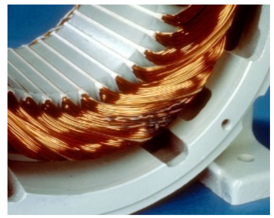
# Generator faults matters



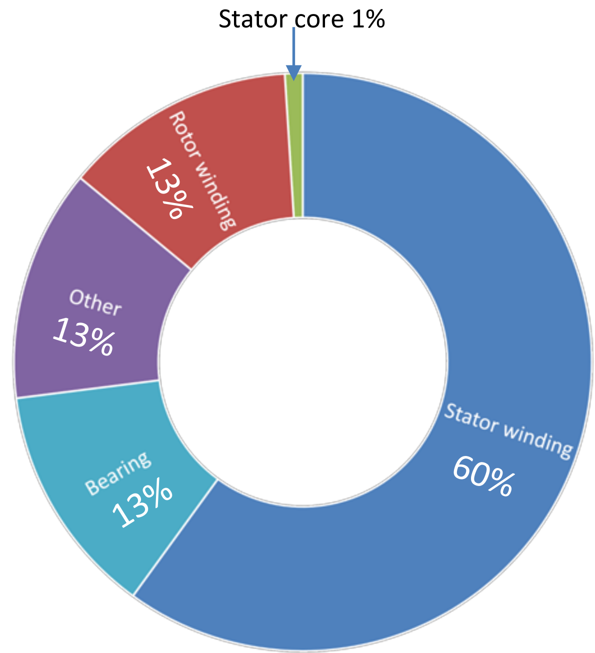
Lost ball bearings

Short in slot section



Short-circuit
in stator windings


Difficult to maintain individual generators in microgrids




Source: Seinsch, H. O. "Monitoring und diagnose elektrischer maschinen und antriebe." *Proc. VDE Workshop*. 2001.

Image sources
Alewine, Kevin. "Wind Turbine Generator Failure Modes." Shermco Industries (2011).
PUNCH, Power failure: Nigerians burn N17.5tn on generators in five years

# In this study, we want to answer…

- How does the slight fault influences the power generation?

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- Is it possible to connect the fault detection methods to the optimal power flow?

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- How does the slight fault influences the power generation?
- Is it possible to connect the fault detection methods to the optimal power flow?
- How can the MSO operate the microgrid in cost-optimal way in faulty-generator scenario?

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# Optimal power flow

Original OPF
→ Function of **healthy generators**

$$\min \sum_{i\in\mathcal{N}} C_i(P_{G_i})$$

subject to

$$P_{G_i,min} \le P_{G_i} \le P_{G_i,max}$$

$$Q_{G_i,min} \le Q_{G_i} \le Q_{G_i,max}$$

$$V_{i,min} \le V_i \le V_{i,max}$$

$$P_i + jQ_i = V_i I_i^*$$

where

$$P_i = P_{G_i} - P_{L,i}$$

$$Q_i = Q_{G_i} - Q_{L,i}$$

# Optimal power flow

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Optimal power flow in faulty-generator scenario
→ Function of **heathy and faulty generators**

$$\min \sum_{i \in \mathcal{N}} \boldsymbol{\tilde{C}_i(P_{G_i})}$$

subject to

$$\boldsymbol{P_{G_i,min}} \leq P_{G_i} \leq \boldsymbol{P_{G_i,max}}$$

$$\boldsymbol{Q_{G_i,min}} \leq Q_{G_i} \leq \boldsymbol{Q_{G_i,max}}$$

$$V_{i,min} \leq V_i \leq V_{i,max}$$

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where

$$P_i = P_{G_i} - P_{L,i}$$

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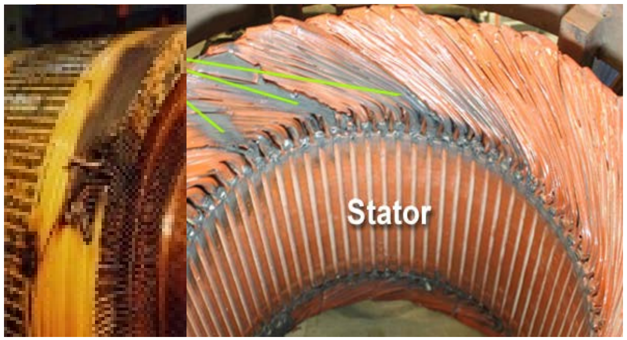
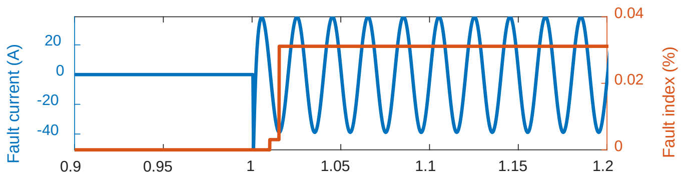
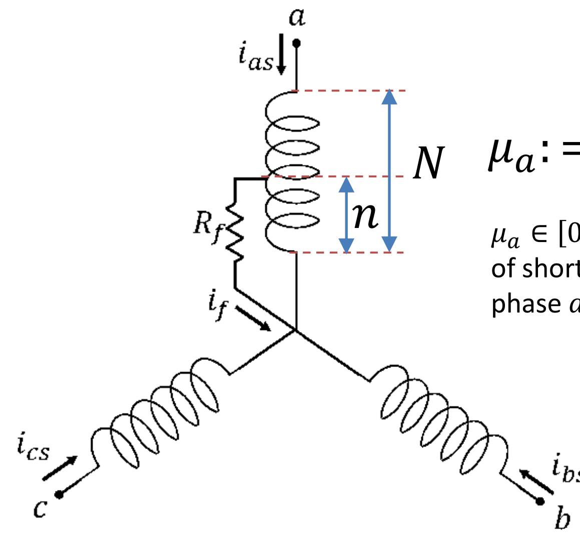
# Effect of incipient fault

## Inter-turn short circuit fault in stator windings




$$\mu_a := \frac{n}{N}$$

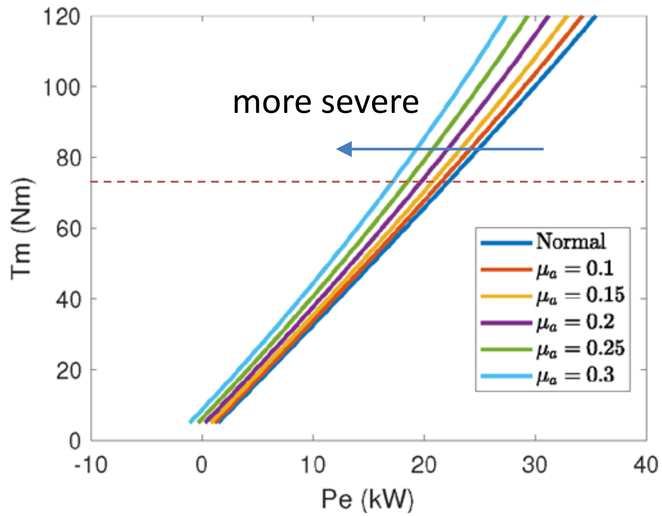
$\mu_a \in [0,1]$: the percentage of short-circuited windings in phase $a$

$$S(\%) = \frac{|\mu_{abc} i_f|}{\sqrt{2}\, I_{rms}}, \quad \mu_{abc} = \begin{bmatrix} \mu_a \\ \mu_b \\ \mu_c \end{bmatrix}$$

S: severity factor


De Angelo, Cristian H., et al. "Online model-based stator-fault detection and identification in induction motors." *IEEE Transactions on Industrial Electronics* 56.11 (2009): 4671-4680.

# Effect of incipient fault



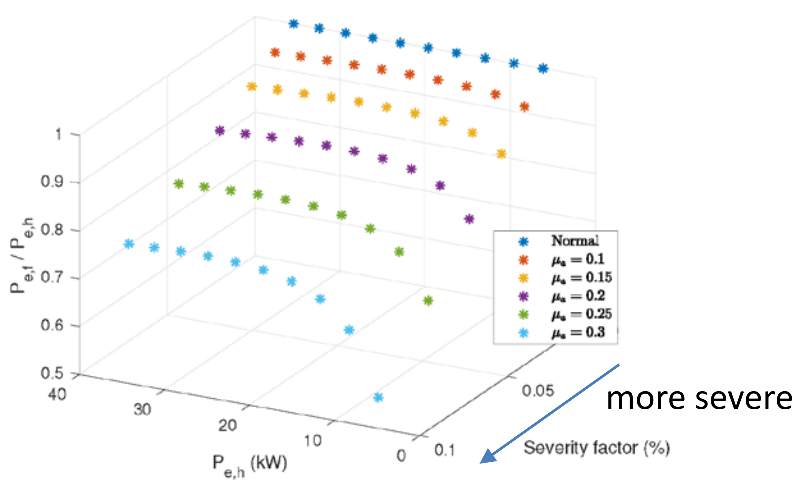
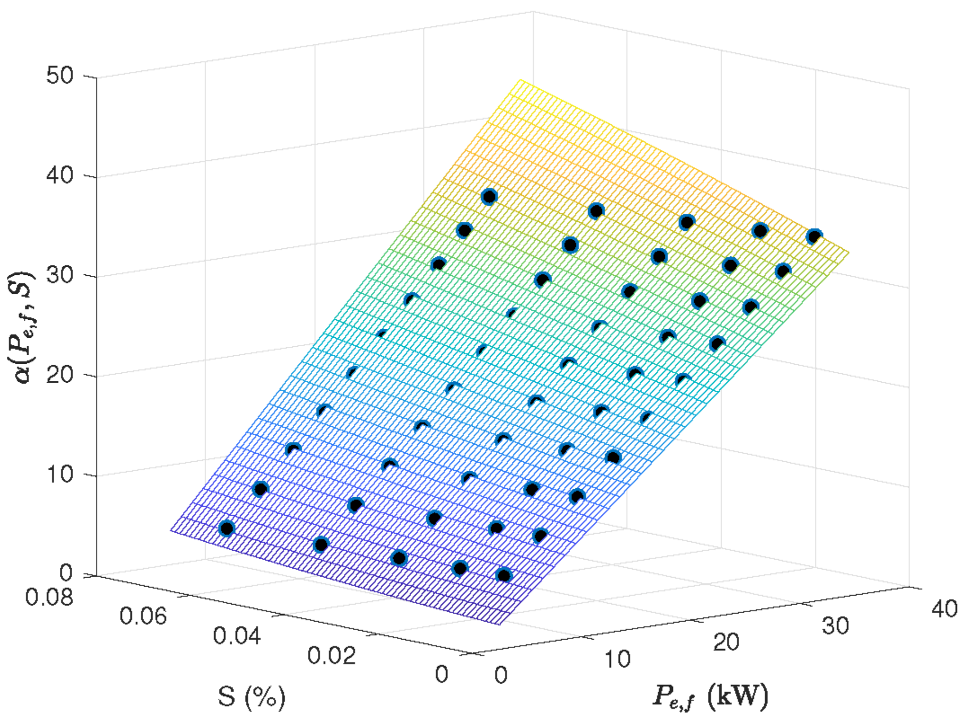




TABLE I
OPERATION CONDITIONS

| Characteristic | Symbol | Value |
|---|---|---|
| Rated power | $p_{nom}$ | 50 kW |
| Rated voltage | $V_{nom}$ | 400 V |
| Number of pole pairs | P | 2 |
| Stator resistance | $R_s$ | 0.2448 Ω |
| Rotor resistance | $R_r$ | 0.4847 Ω |
| Stator inductance | $L_s$ | 80.76 mH |
| Rotor inductance | $L_r$ | 82.12 mH |
| Mutual inductance | $L_m$ | 77.2 mH |
| IG inertia | $J$ | 0.1 kg/m$^2$ |
| Grid normal frequency | $f_e$ | 50 Hz |

# OPF as a function of severity factor




$$P_{G,i} = \alpha_i(P_{G_f,i}, \mathbf{S}_i)$$

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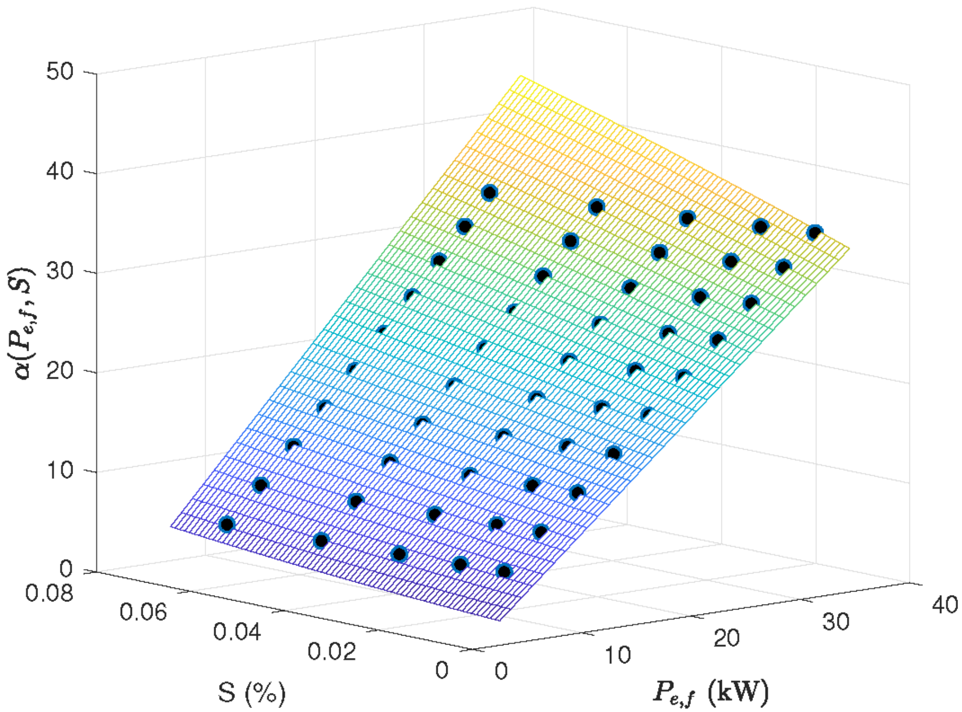
# OPF as a function of severity factor




$$P_{G,i} = \alpha_i(P_{G_f,i}, \mathbf{S}_i)$$

$$\alpha_i\left(P_{G_f,i}, \mathbf{S}_i\right) \approx P_{G_f,i}\left(a_{1,i} + a_{2,i}\mathbf{S}_i + a_{3,i}\mathbf{S}_i^2\right)$$

Polynomial approximation

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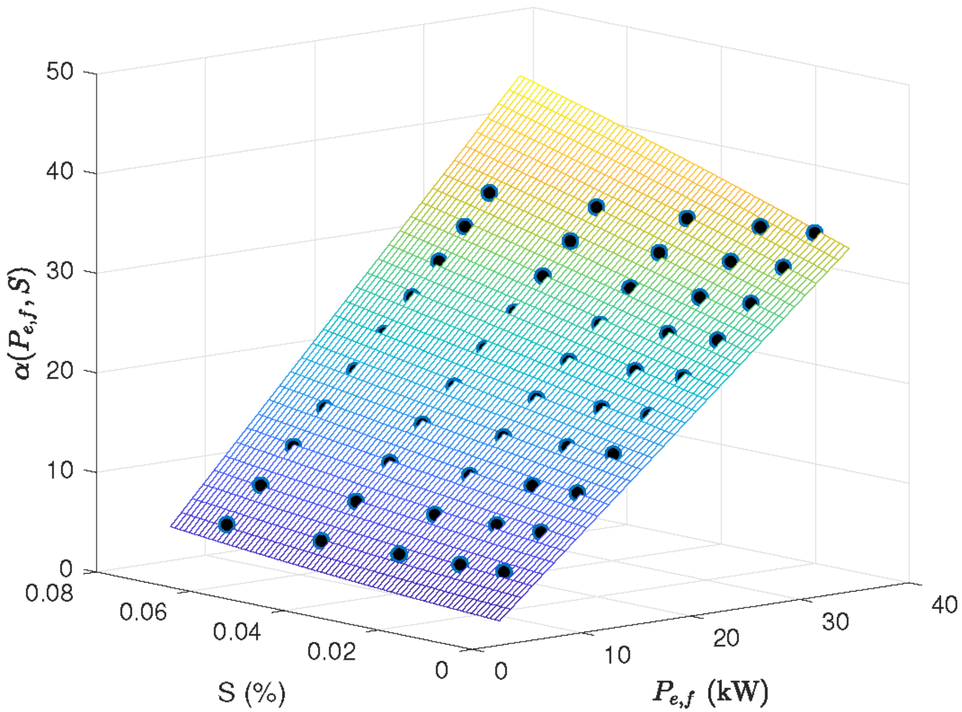
# OPF as a function of severity factor

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Polynomial approximation

Optimal power flow
→ Function of the power of **heathy/ faulty generators and its severity**

$$\min \sum_{i\in\mathcal{N}} \boldsymbol{C_i}\left(\boldsymbol{P_{G_i}}, \mathbf{S}_i\right)$$

subject to

$$\boldsymbol{P_{G_i,min}}(\mathbf{S}_i) \le P_{G_i} \le \boldsymbol{P_{G_i,max}}(\mathbf{S}_i)$$

$$\boldsymbol{Q_{G_i,min}}(\mathbf{S}_i) \le Q_{G_i} \le \boldsymbol{Q_{G_i,max}}(\mathbf{S}_i)$$

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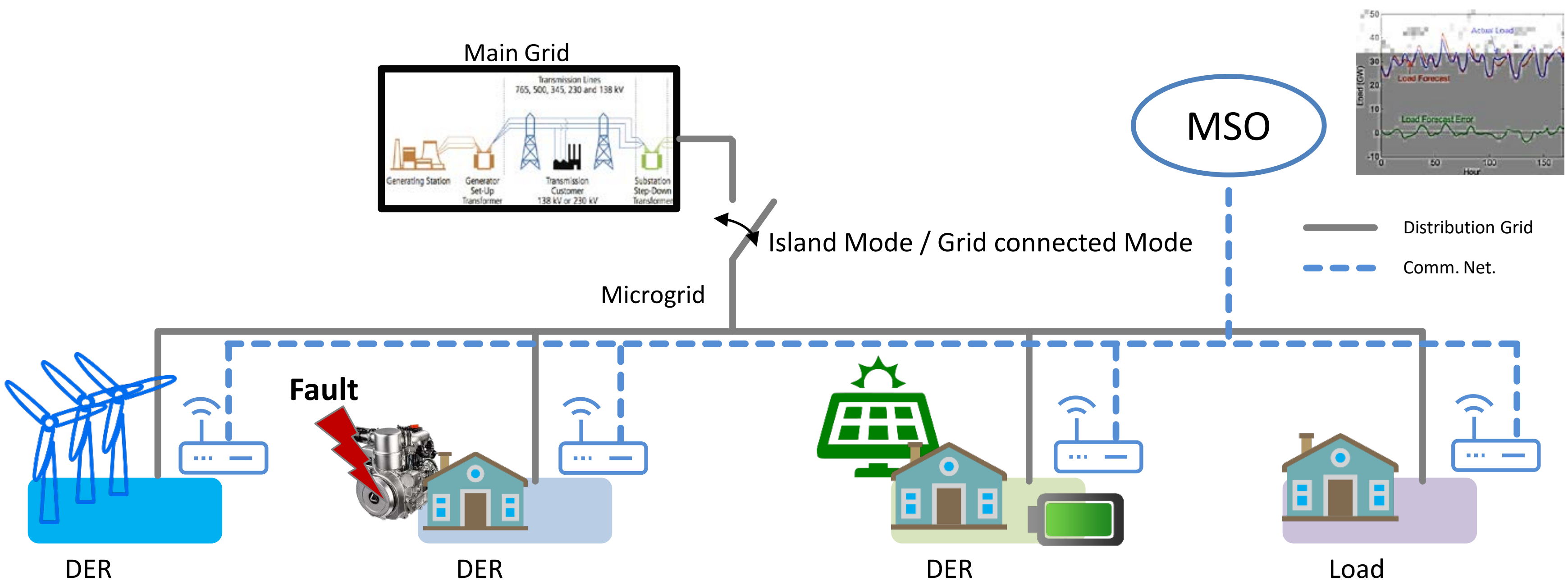
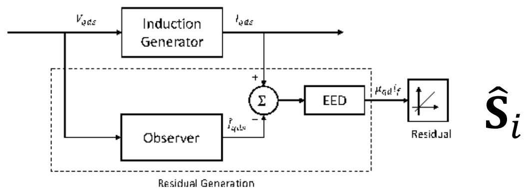
# Severity estimation and OPF



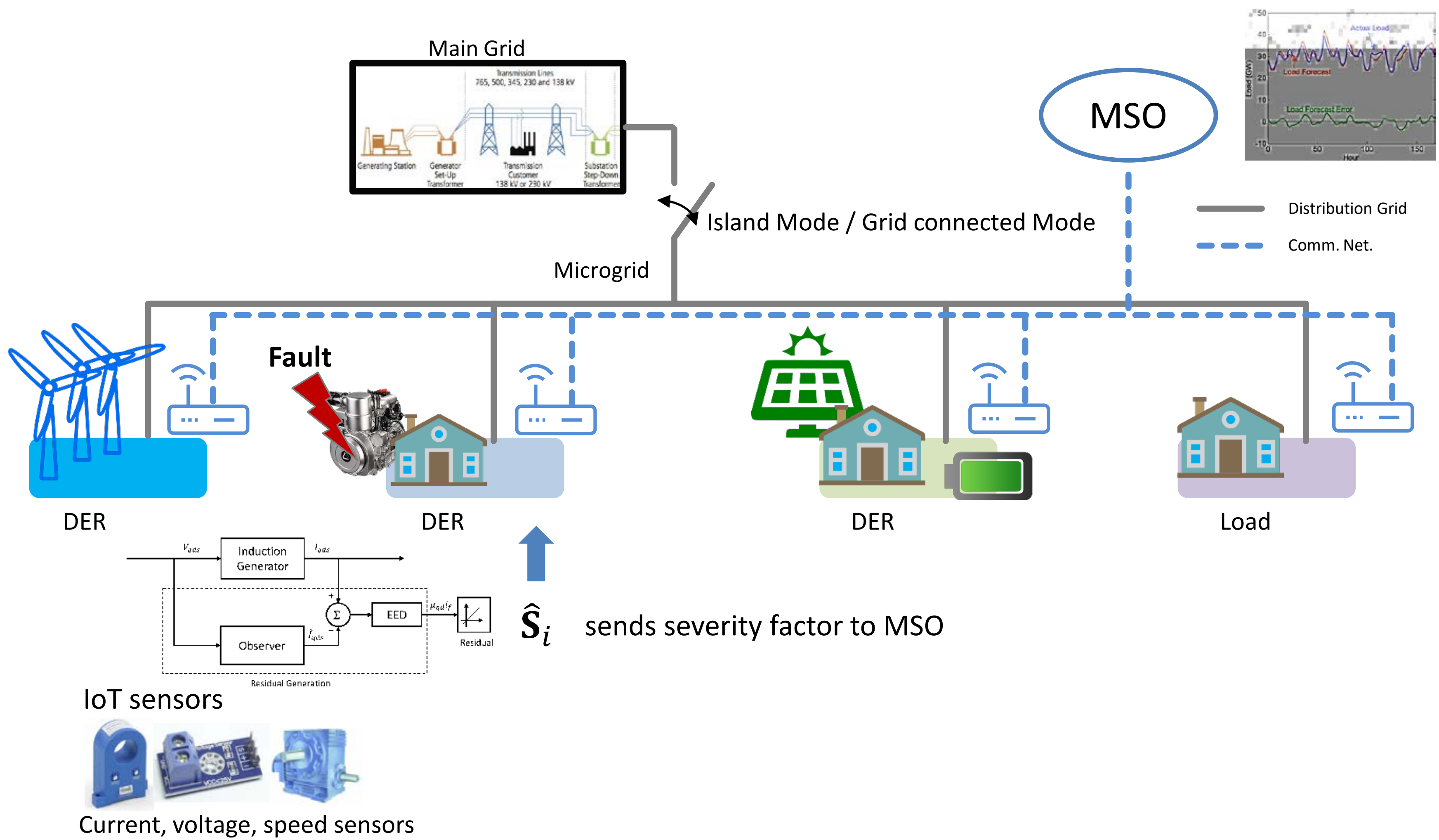




IoT sensors

Current, voltage, speed sensors


De Angelo, Cristian H., et al. "Online model-based stator-fault detection and identification in induction motors." *IEEE Transactions on Industrial Electronics* 56.11 (2009): 4671-4680.

# Severity estimation and OPF

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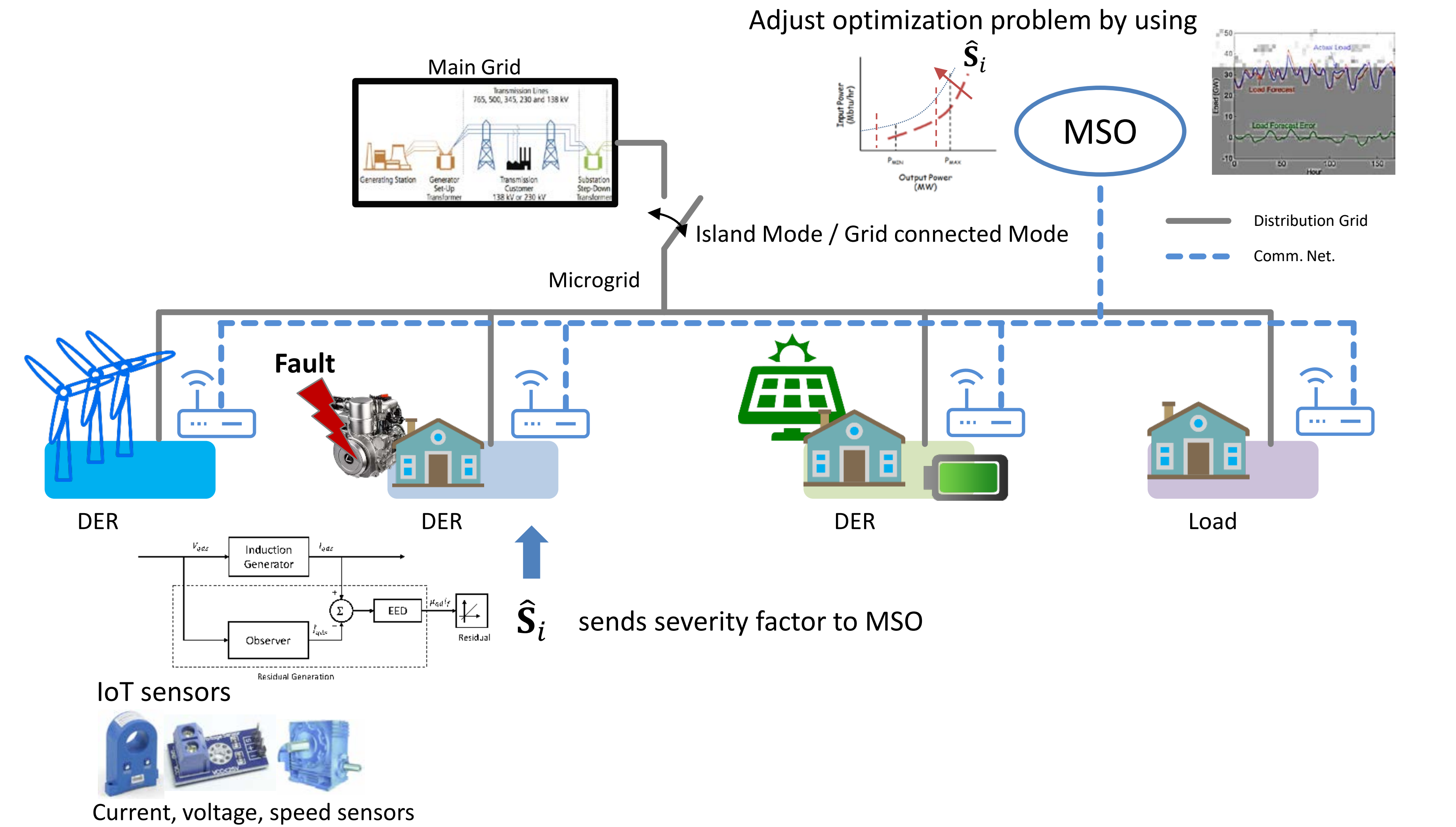


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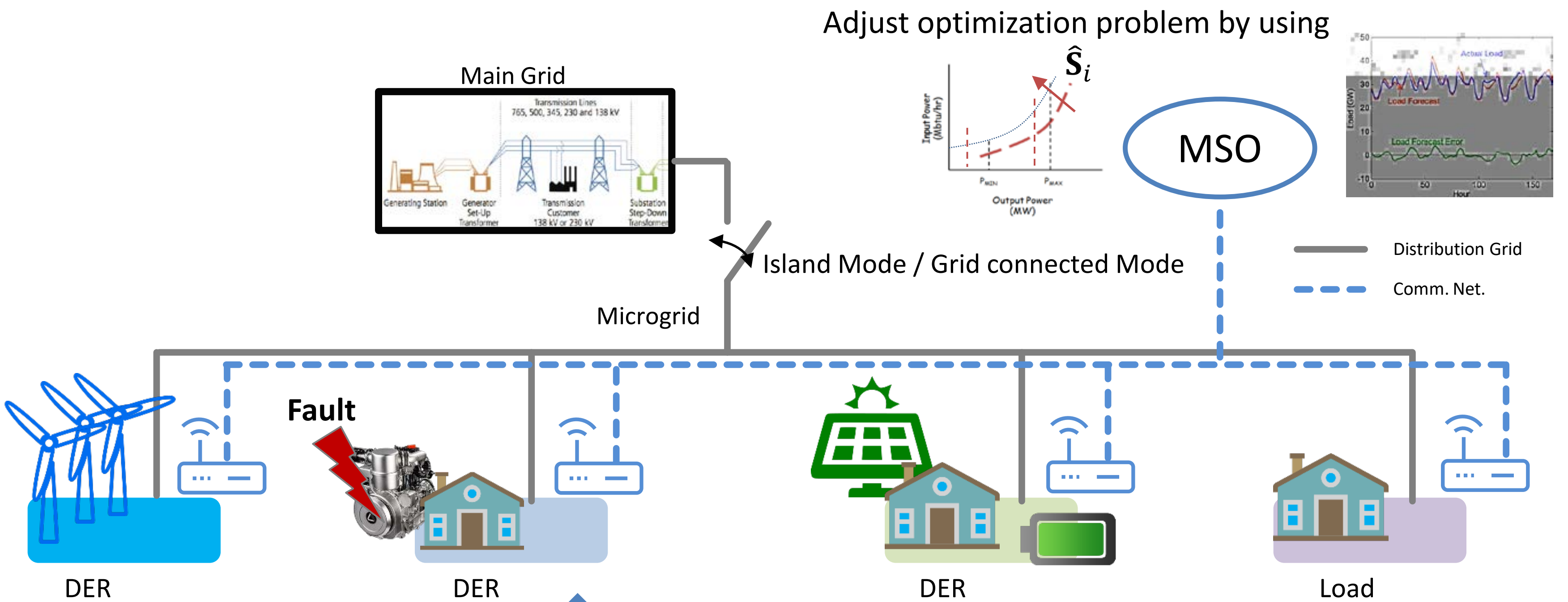


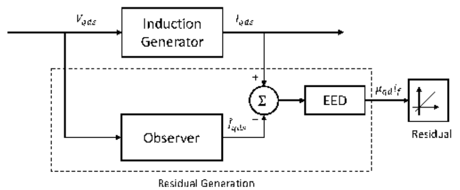


$\hat{S}_i$ sends severity factor to MSO

MSO solve OPF using faulty information

$$\min \sum_{i \in \mathcal{N}} C_i(P_{G_i}, S_i)$$

subject to

$$P_{G_i,min}(S_i) \le P_{G_i} \le P_{G_i,max}(S_i)$$
$$Q_{G_i,min}(S_i) \le Q_{G_i} \le Q_{G_i,max}(S_i)$$
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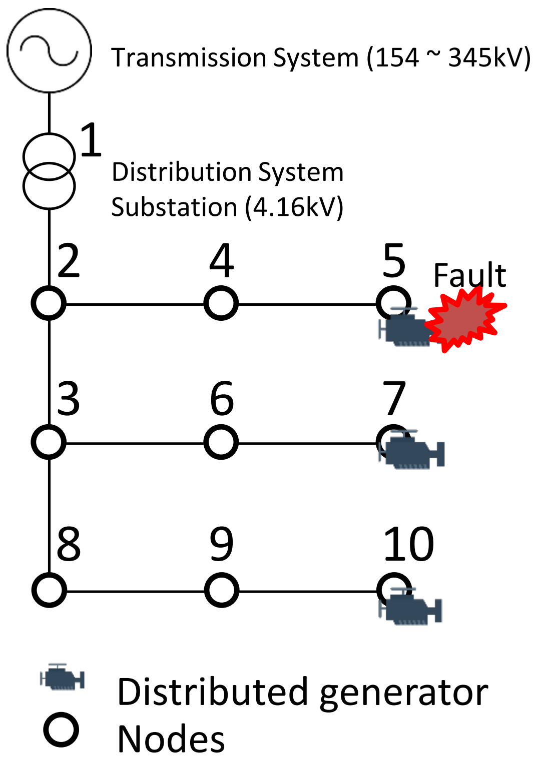
# Case Study

## 10 node Microgrid

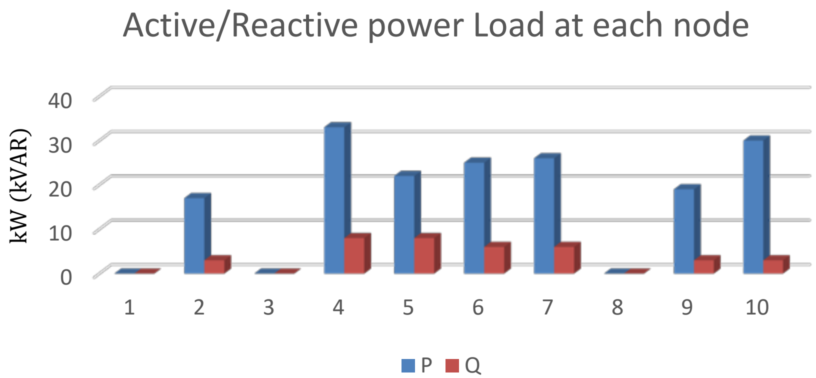



**Simulation parameters**

Line impedance:
$Z_{mn} = 0.4576 + j1.078$

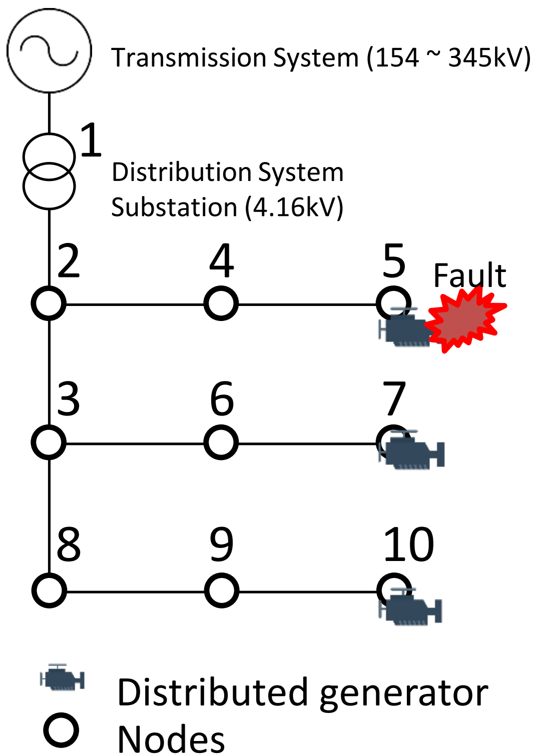
Coefficients for quadratic generation cost
$c_{2,i} = 200, c_{1,i} = 40, c_{0,i} = 1, i \in \{1,5,7,10\}$

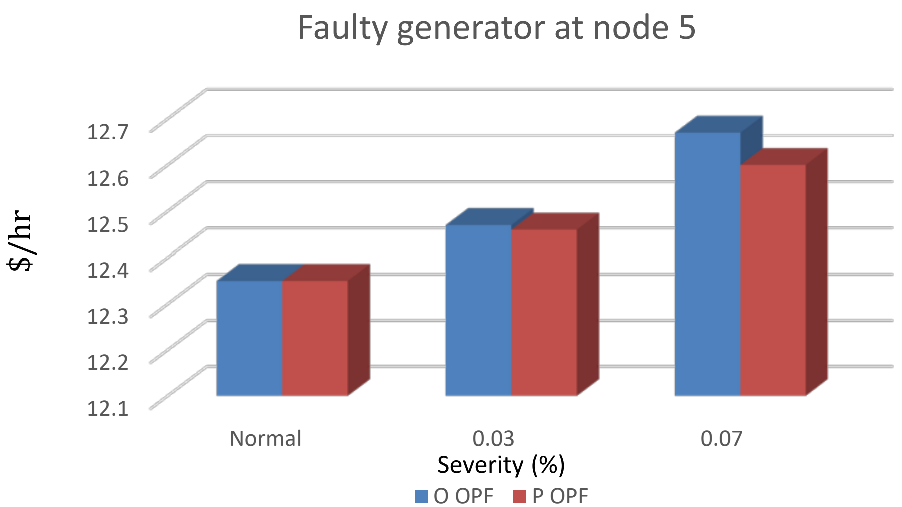
Generation power limits of healthy generators
$P_{\min,i} = 5$ kW, $P_{\max,i} = 50$ kW



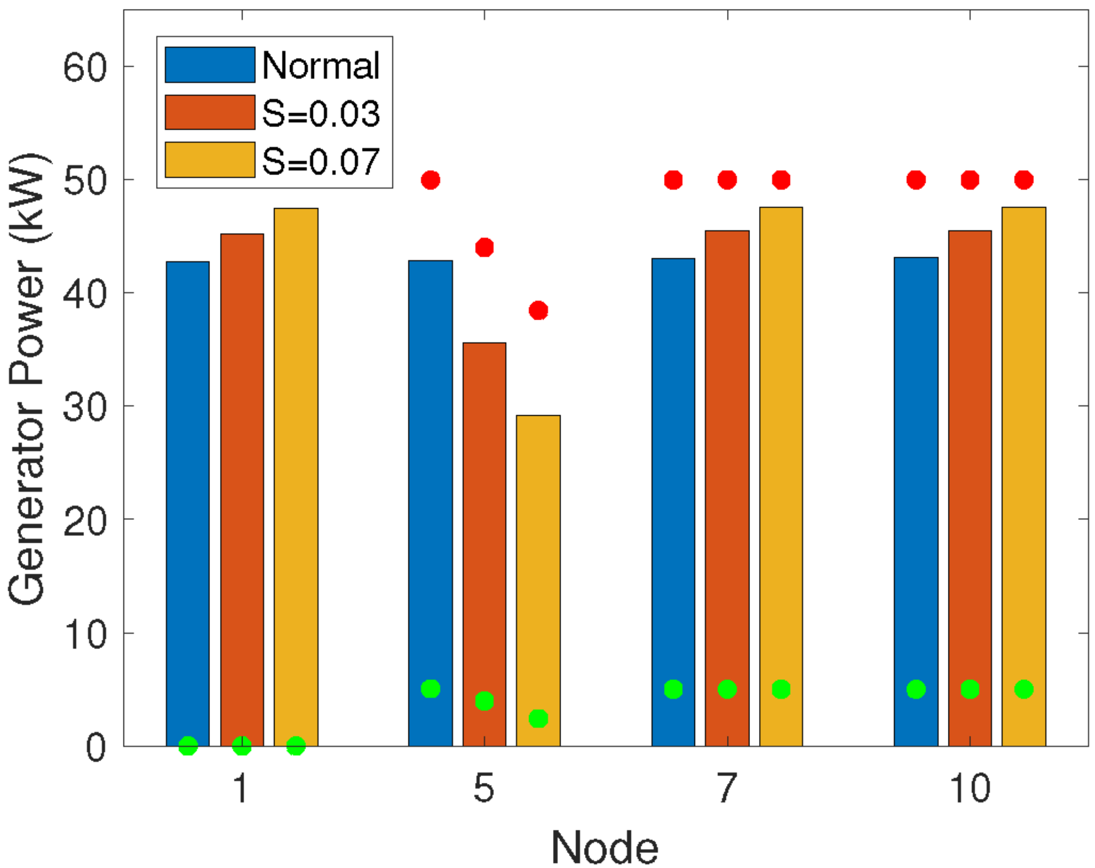
# Comparison of total costs against original OPF

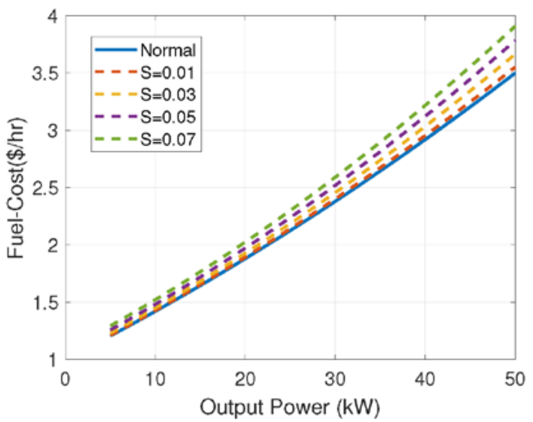
## ■ 10 node Microgrid

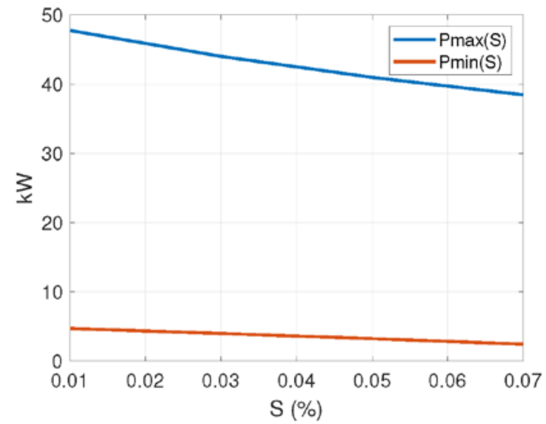


# Power dispatches with generator fault at node 5



# Conclusion

- Concerned the tertiary control of microgrids in a faulty-generator scenario

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# Conclusion

- Concerned the tertiary control of microgrids in a faulty-generator scenario
- Investigated how the inter-turn short circuit fault affects to power generation
- The optimal power flow problem in a faulty-faulty generator scenario is formulated as a function of generation of faulty generators and its severity factor
- The proposed optimal power flow algorithm provides less operation cost compared to the original one in faulty-generator scenario

**Thank you for listening!**
**Q&A**

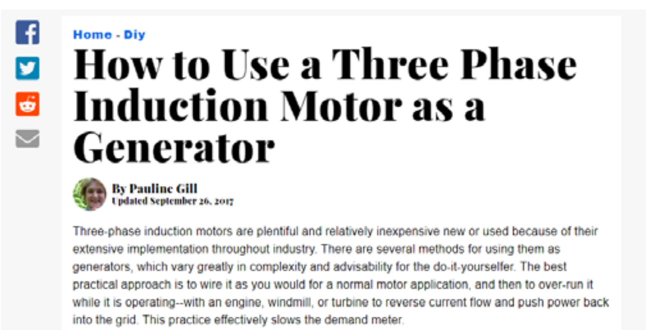
# Diesel and induction generator

Direct Current Microgrid Power Modeling and Control
Manuela Sechilariu, Fabrice Locment, in Urban DC Microgrid, 2016
3.6 Diesel Generator Operating Mode Modeling
The diesel generator is used as a backup source only in the off–grid mode of the DC microgrid.

https://homesteady.com/how-12055415-make-own-3phase-converter.html

**Energizing Renewable Energy Systems and Distribution Generation**
T. Adefarati, R.C. Bansal, in Pathways to a Smarter Power System, 2019

2.4.3 Diesel Generator
Diesel generators can be utilized as standalone, emergency, standby, and peak shaving units because of the following characteristics: availability, quick start up, reliability, fast ramp up, durability, etc. [8]. The diesel generators have high operating cost and generate electricity on demand when compared with renewable DERs.


Home - Diy

How to Use a Three Phase Induction Motor as a Generator

By Pauline Gill
Updated September 26, 2017

Three-phase induction motors are plentiful and relatively inexpensive new or used because of their extensive implementation throughout industry. There are several methods for using them as generators, which vary greatly in complexity and advisability for the do-it-yourselfer. The best practical approach is to wire it as you would for a normal motor application, and then to over-run it while it is operating--with an engine, windmill, or turbine to reverse current flow and push power back into the grid. This practice effectively slows the demand meter.

Wind Turbine Components and Descriptions
R. Nolan Clark, in Small Wind, 2014
Synchronous generators are not normally used on small wind machines because of the additional equipment needed to make them operate efficiently.

# References

- Image sources
  - http://engineering.electrical-equipment.org/electrical-distribution/electric-load-forecasting-advantages-challenges.html

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# Generator faults matters