Study on Impact of

Distributed Grid-connected PV System on Distribution Network

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CSG Energy
Renewable Energy Business Department

中国南方电网
CHINA SOUTHERN POWER GRID

南网能源
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Background

Why do we need renewable energy?

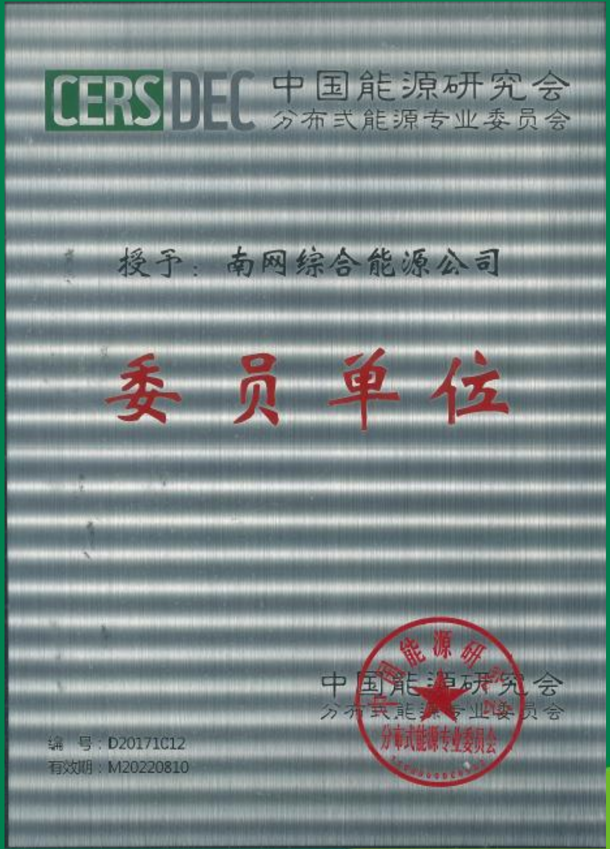
- Less or none CO_2 emission (against Global Warming issue);
- Give clean energy for people demand (against World Energy Crisis issue);

Most common renewable energy forms?

- Wind Power
- Solar Power (PV system)

Brief Introduction

- Established on Dec, 20th, 2010, headquarter located in Guangzhou.
- Solar Power-one of several main businesses
- A member of CERS (China Energy Research Society)
- Biggest roof-top PV system owner and operator in China, even around the world
- By Nov. 2017, running 67 projects up to 400MW(mainly distributed solar power), others 220MW under construction



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Rewarded Projects

Shunde Midea Cooling Factory Roof-Top Solar Power Plant

- Installed capacity: 31.257MW
- COD(Commercial Operation Date): Apr,25th,2015
- The largest Commercial Roof-Top PV system until Sep,30th,2015
- By Oct, 2017, generated 106 million kwh electricity
- Special Award of Distribution Power Project in China for 2015, the only rewarded PV project

Rewarded Projects

Zhongshan Galanz Factory Roof-Top Solar Power Plant

- Installed capacity: 52.377MW
- COD: Sep,30th,2015
- Largest Commercial Roof-Top PV system
- By Oct, 2017, generated 116 million kwh electricity
- First Class Award of Distribution Power Project in China for 2017

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Rewarded Projects

Dongfeng Nissan Factory Carport Solar Power Plant

- Installed capacity: 27.53MW
- COD: Dec,22nd,2016
- By Oct, 2017, generated 29 million kwh electricity
- First Class Award of Distribution Power Project in China for 2017

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Grid connection rule

- PV system capacity and grid-connecting voltage should be well coordinated.
- In CSG area, grid-connecting rules are shown on table.

System capacity (kWp)	Recommended grid connecting voltage (kV)
Not greater than 8	0.22
8 to 500	0.38
500 to 6000	10(6)
6000 to 10000	City:10(20)
	Countryside:35
10000 to 30000	City:10(20) or 110
	Countryside:35 or 110
30000 to 100000	110
100000 and above	110 or 220

Impacts

What issues might we face if PV system connects to distributed power grid?

- Energy flow alternation
- Power quality
- Relay co-ordination

Energy flow

Traditional distributed power grid:

Power Plant

↓

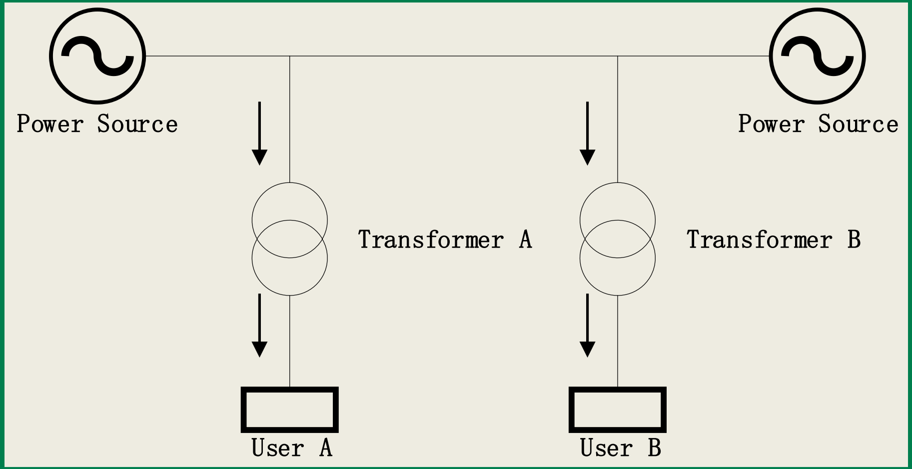
Main Power Grid

↓

Distributed Power Grid

↓

User



Energy flow

PV system tapped in :

Power Plant

↓

Main Power Grid

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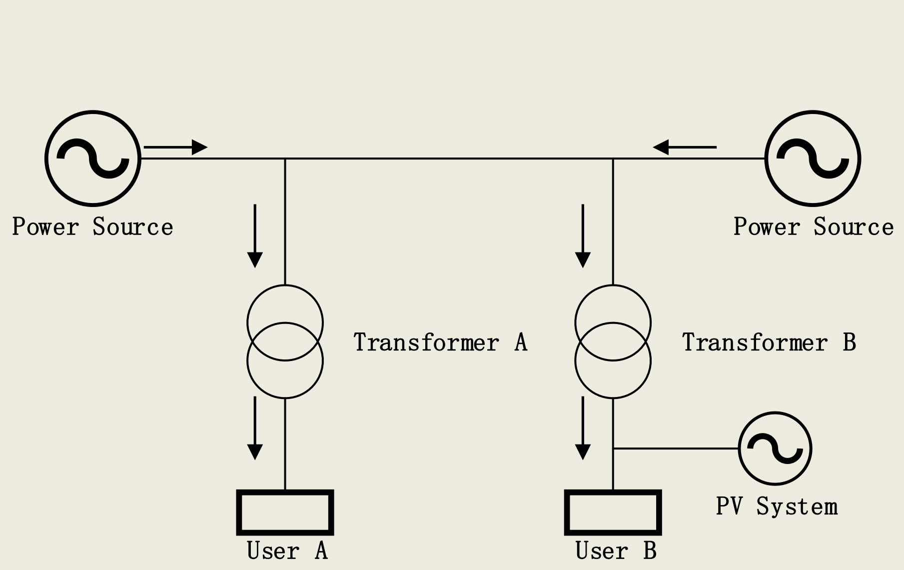
Distributed Power Grid ⟷ PV System

↓

User



Power quality

- Voltage deviation
- Frequency deviation
- Voltage fluctuation and flicker
- Three phase voltage unbalance
- Harmonics

Voltage deviation

- Mainly re-active power concern;
- PV system re-active power output might leads network voltage raise
- Closest busbar & Up-stream Transformer are most effected

$$\Delta U = \beta(r_k^* \cos\varphi_2 + x_k^* \sin\varphi_2) \times 100\%$$

β: Transformer loading current proportion

r_k^* : Transformer winding voltage drop proportion

x_k^* : Transformer excitation voltage drop proportion

φ_2 : Secondary winding voltage-current angle difference

Frequency deviation

- Mainly active power concern;
- Inverter high power factor setting makes more active power output
- PV system active power output might leads network frequency raise

Voltage fluctuation and flicker

- PV system output depends on sunlight intensity
- Unstable power output leads to voltage fluctuation and flicker

Three phase voltage unbalance

- Three phase voltage unbalance mostly caused by unbalance loading

Harmonics

- PV system inverter produced in constrained way limits minimum harmonics issue
- Test Report of National Quality Supervision and Testing Center for Solar Photovoltaic Products (Guangdong) for one of our projects shows that PV system meets power grid’ s requirement

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National Quality Supervision and Testing Center for Solar Photovoltaic Products (Guangdong)

检 验 报 告（Test Report）

表 14-2 组串式系统检测结果汇总记录表

编号	测试项目	分项和说明	检测结果	合格判定标准	结论
1	光伏组串污渍和灰尘损失	——	最大值：2.8%	≤5%	P
2	光伏系统串联失配损失	组件-组串	最大值：0.81%	≤1%	P
3	光伏组串温升损失	——	最大值 20.91%（温度 60.1℃）	——	N/A
4	热斑组件功率损失	选定热斑严重组件	见附件 9	——	N/A
5	光伏方阵间遮挡损失	——	见附件 8	——	N/A
6	交流线损	逆变器-变压器	0.61%	≤1.5%	P
		交流汇流箱-并网点	1.29%	≤1.5%	P
7	逆变器中国加权效率	20 kW 逆变器	96.5%	插值法 96.51	N/A
8	并网点电能质量	20 kW 逆变器	电压偏差最大值：3.67%	小于±7%	P
			频率偏差最大值：0.037 Hz	±0.5 Hz	P
			总谐波电流畸变最大值：5.30%	输出额定功率时小于 5%	N/A
			三相不平衡度最大值：1.20%	不超过 2%	P
9	功率因数	正常工作状态，组串式系统并网点	0.93	——	N/A
10	光伏方阵绝缘阻值测试	正极对地（单个组串）	最小值：43.0 MΩ	≥1 MΩ	P
		负极对地（单个组串）	最小值：77.0 MΩ	≥1 MΩ	P
11	接地连续性测试	交流汇流箱	最大值：0.98 Ω	<4 Ω	P
		支架	最大值：1.23 Ω		
		组件	最大值：1.68 Ω		
		线槽	最大值：1.09 Ω		

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Relay co-ordination

- One-way energy flow protection might changed to double-way’ s
- Original settings might be re-calculated
- Additional fault-current
- Necessary devices/gears upgradation
- More relay co-operation, more complex system consideration

Required relays & function

- AC Time Overcurrent Relay (50)
- Instantaneous Overcurrent Relay (51)
- Under Voltage Relay (27)
- Over voltage Relay (59)
- Under/Over Frequency Relay (81)
- Transformer Thermal Relay (49, only applied when transformer is installed)
- Low voltage ride through, LVRT
- Anti islanding (applied for grid-connection PV system)

Simulation

Simulate a simplified power grid, due to software module limitation, we mainly focus on 2 impact spots.

- Energy flow
- Voltage deviation

Model

A two 110kV incoming switchyard (1000MVA 3-phases short circuit capacity for each one).

Two 110kV busbars (One tie-breaker)

Two 110/10kV step-down transformers (tap at 110/10.5kV).

Two 10kV busbars and serval 10kV feeders (One tie-breaker)

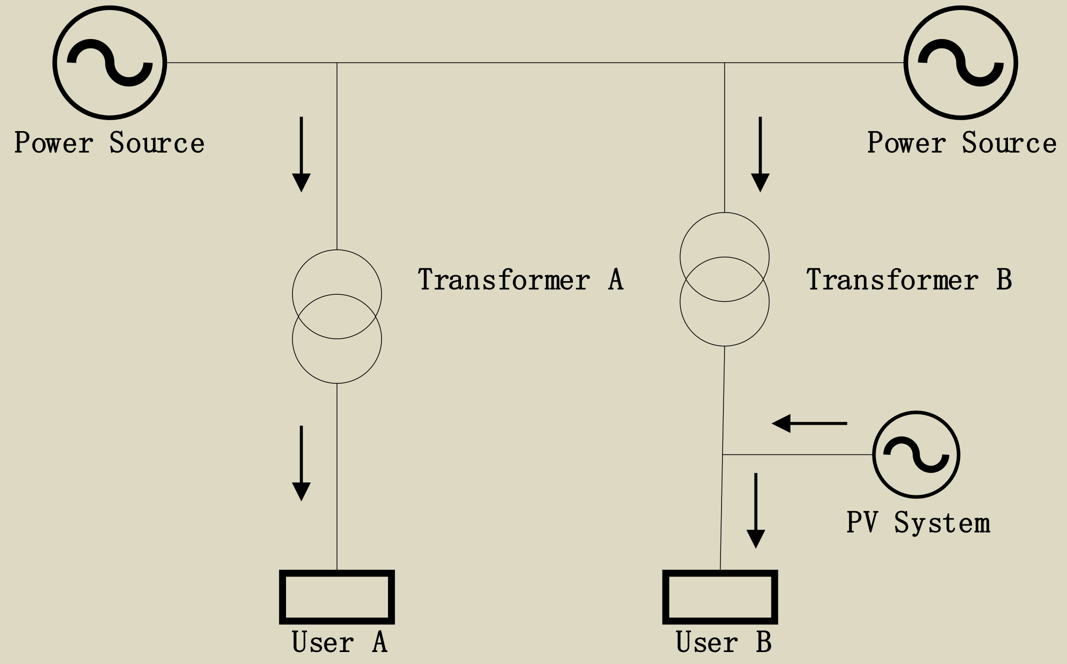
User A (15MW+5Mvar) fed by busbar A

User B (15MW+5Mvar) fed by busbar B

A PV system (AC output rated 10kV) connects to the grid a User B end

Case 1

- PV system has 6600 panels (175.7 Watt/Panel)
- Inverters (each at 99% efficiency, power factor setting at 0.98)
- Approximated 1141.71kW output at maximum
- PV system capacity far less than User B demand (15MW+5Mvar)



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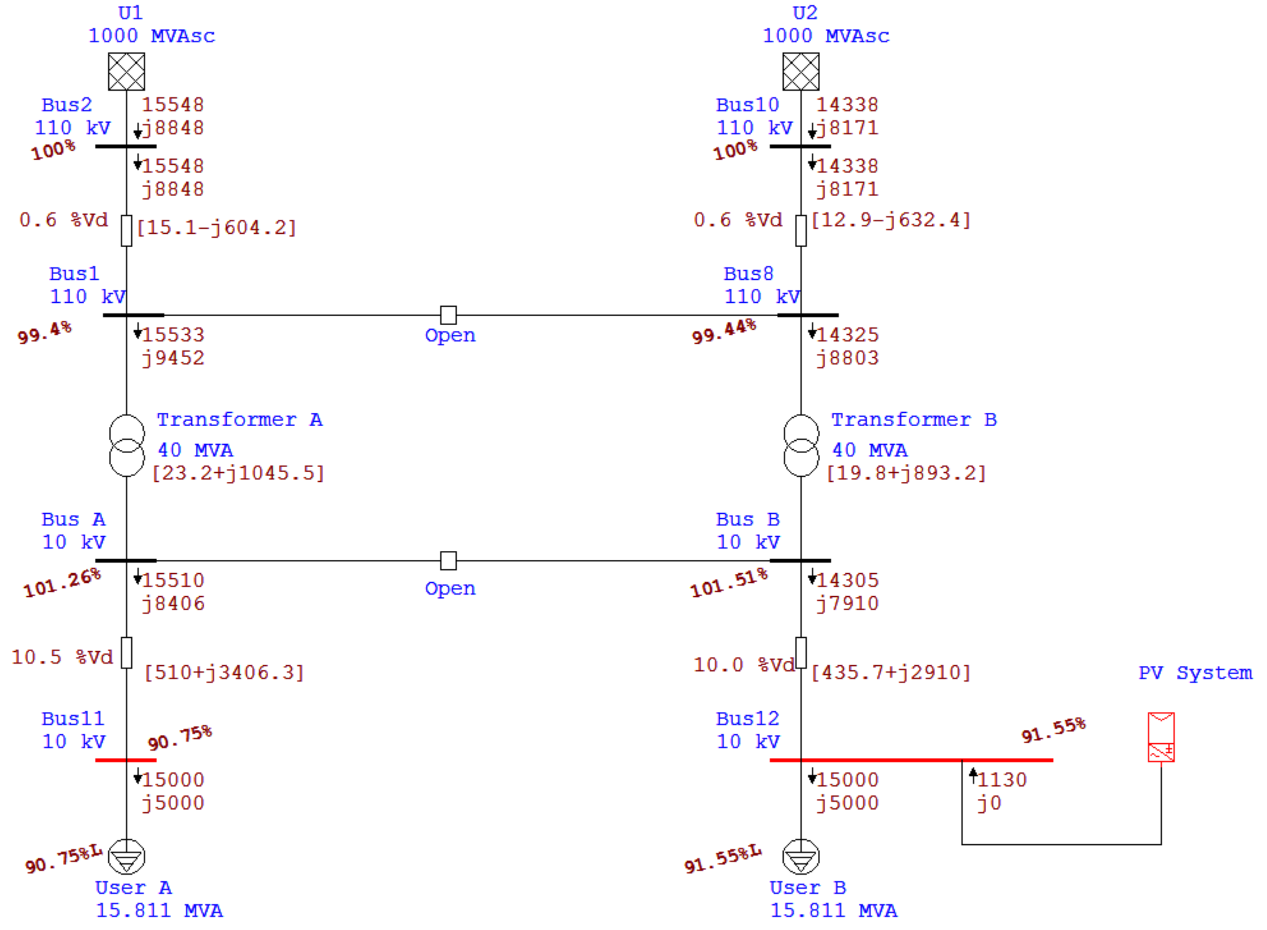
Case 1



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Case 1

- Energy Flow:

  PV & Grid → User B

- Voltage

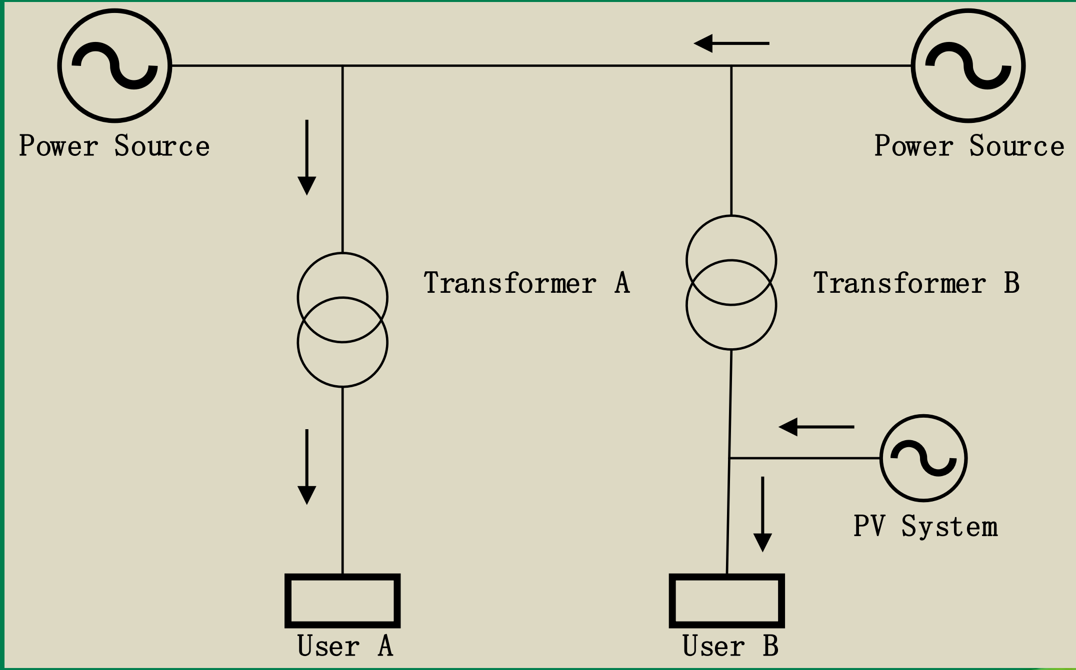
  Busbar B voltage raises

  User B terminal voltage raises

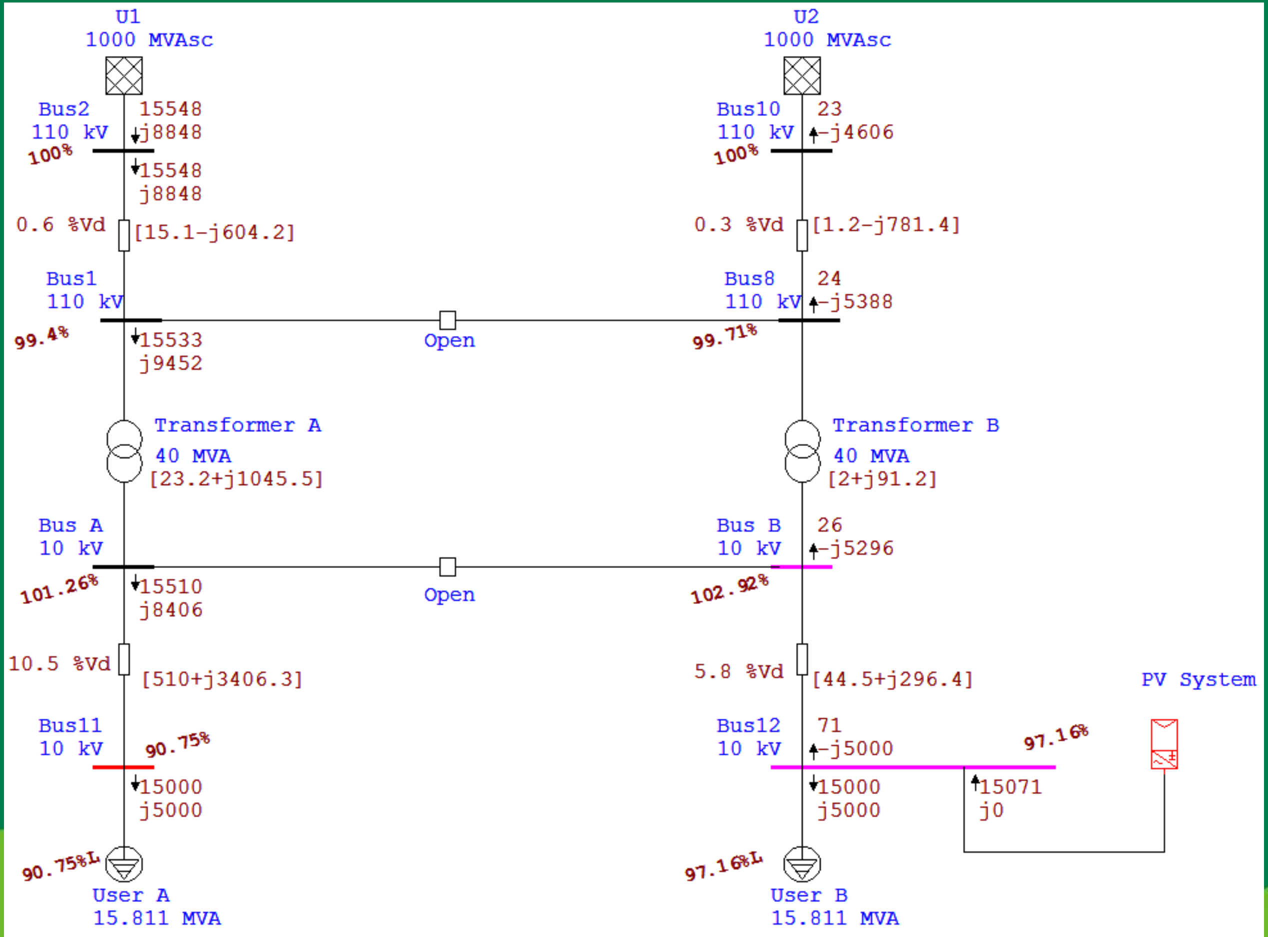
  Transmission line voltage drop and power consumption reduced

Case 2

- PV system has 88000 panels (175.7 Watt/Panel)
- Inverters (each at 99% efficiency, power factor setting at 0.98)
- Approximated 15222.82kW output at maximum
- PV system capacity closed to User B demand (15MW+5Mvar)



Case 2



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Case 2

- Energy Flow:

  PV → User B

- Voltage

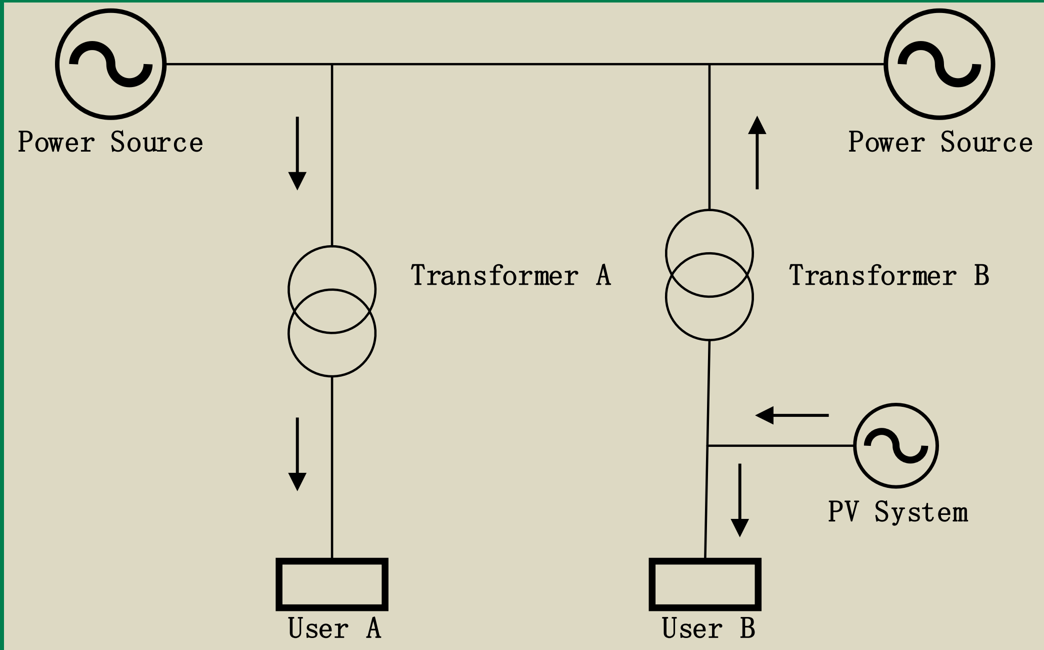
  Busbar B voltage raises might lead to over-voltage

  User B terminal voltage raises might lead to over-voltage

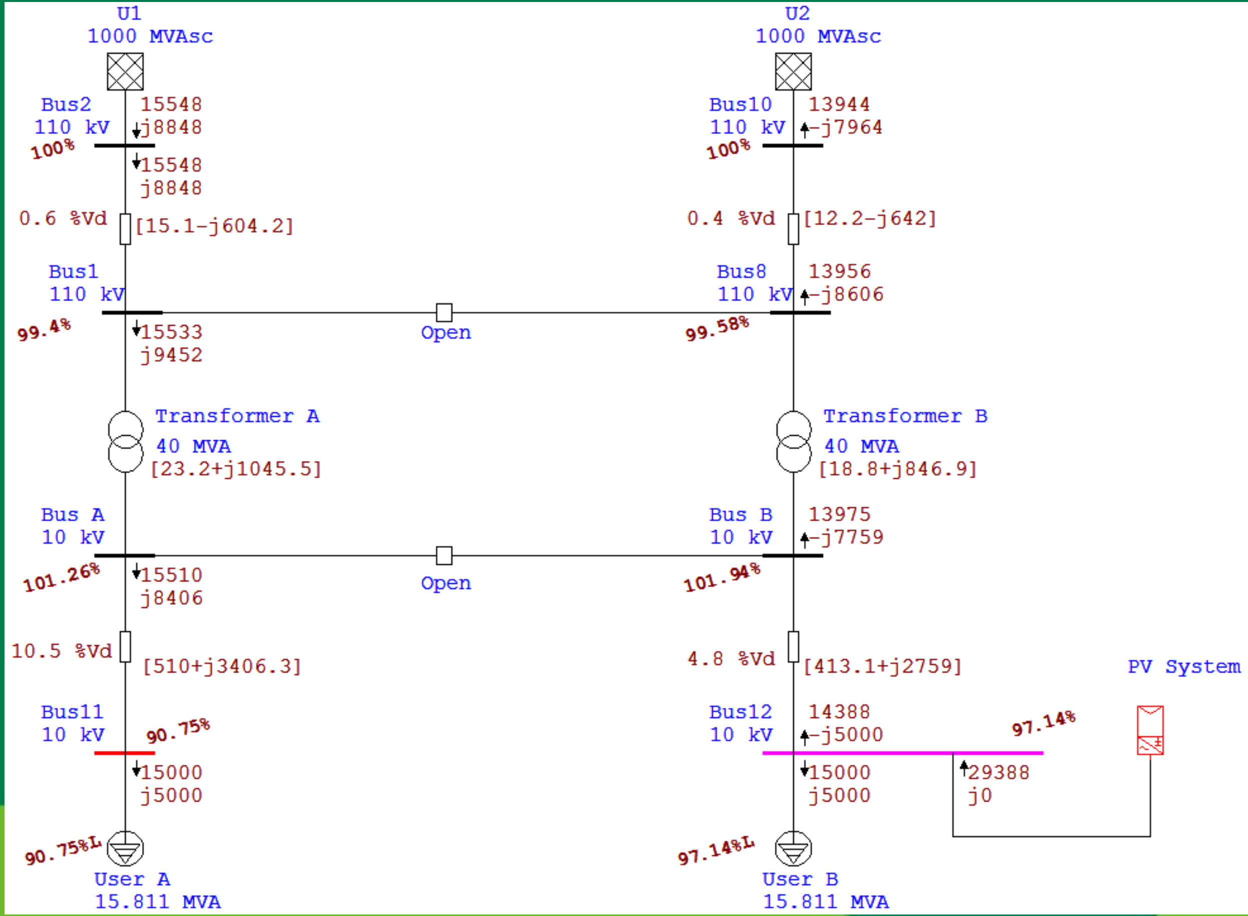
  Transmission line voltage drop and power consumption reduced to 0 at lowest

Case 3

- PV system has 171600 panels (175.7 Watt/Panel)
- Inverters (each at 99% efficiency, power factor setting at 0.98)
- Approximated 29684.5kW output at maximum
- PV system capacity much greater than User B demand (15MW+5Mvar)



Case 3



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Case 3

- Energy Flow:

  PV → User B & Grid

- Voltage

  Busbar B voltage raises

  User B terminal voltage raises

  Transmission line voltage drop and power consumption reduced

Conclusion

- PV system output equals User demand, Voltage maximum raised
- Larger PV system, greater distributed-power-grid voltage & frequency fluctuation impact
- A proper proportion of step-down transformer capacity and PV system capacity shall be considered
- Energy storage helps stabilizing power grid frequency
- Re-active compensation also helps stabilizing power grid voltage

Thanks!

China Southern Power Grid ENERGY-EFFICIENCY & CLEAN-ENERGY Co., Ltd.