

**Grand Challenges in Electric  
Power Engineering:  
*Extreme System Reliability***

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- **Electric power quality**
- **Extreme bus voltage reliability, for example 'five nines' (i.e., 0.99999 availability), or six nines or even higher**
- **Utilization of new transmission and distribution technologies for improvement of reliability**
- **Utilization of distributed energy sources (DERs) to improve reliability**
- **Working with manufacturers of information technology equipment to reduce load vulnerability**
- **Distributed rather than concentrated loads**
- **Loop circuits for distribution systems**
- **Information Technology and sensitive manufacturing loads**
- **Independence of energy sources**
- **Environmental issues**

# 7/24 UTILIZATION OF POWER SYSTEM ULTRA HIGH RELIABILITY



INFORMATION PROCESSING, FINANCIAL  
SERVICES, AIRLINES, POLICE, MILITARY

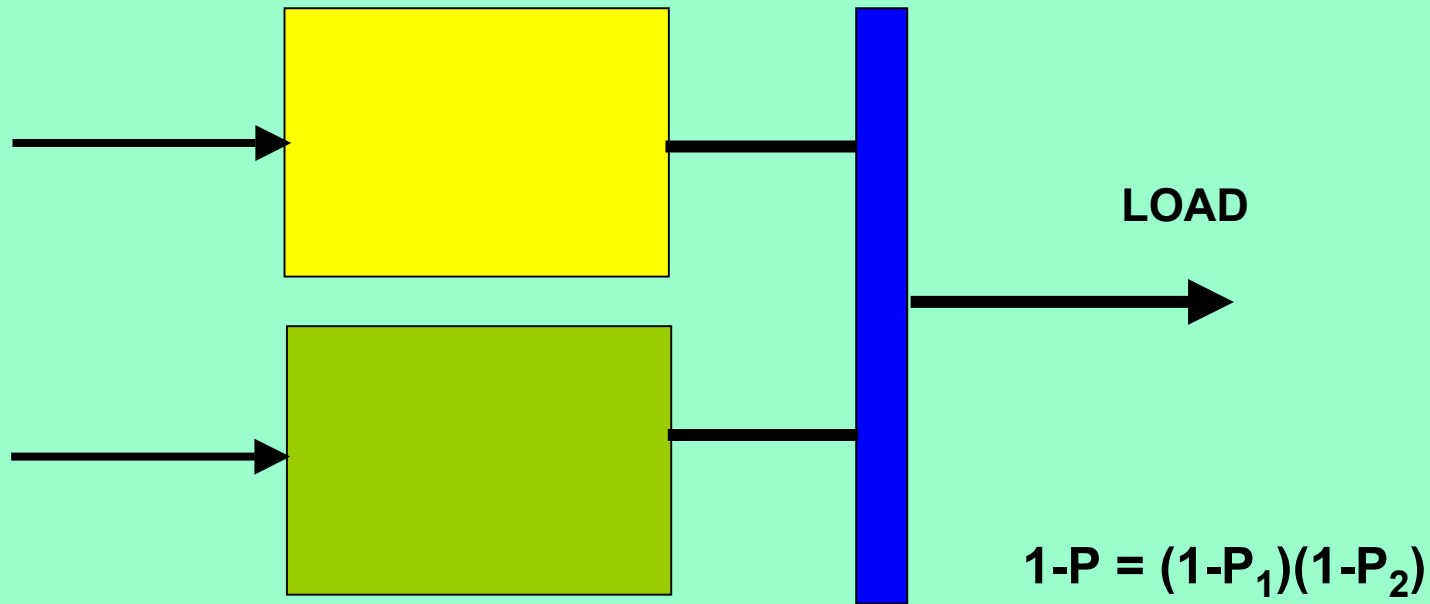


AMERICAN  
STOCK EXCHANGE  
Equities Options ETFs

Edward Jones

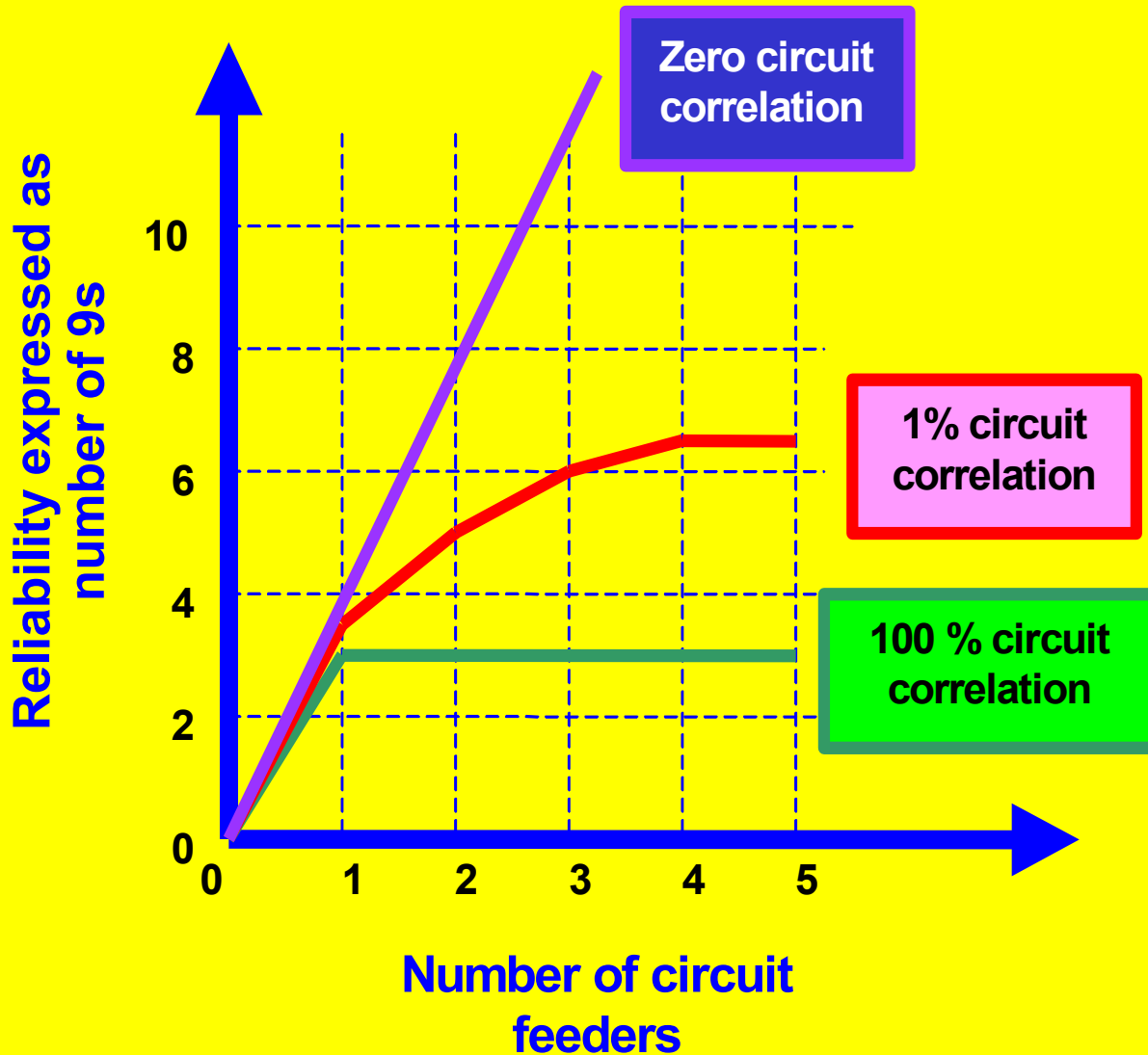
Charles Schwab

# INDEPENDENCE OF SOURCES

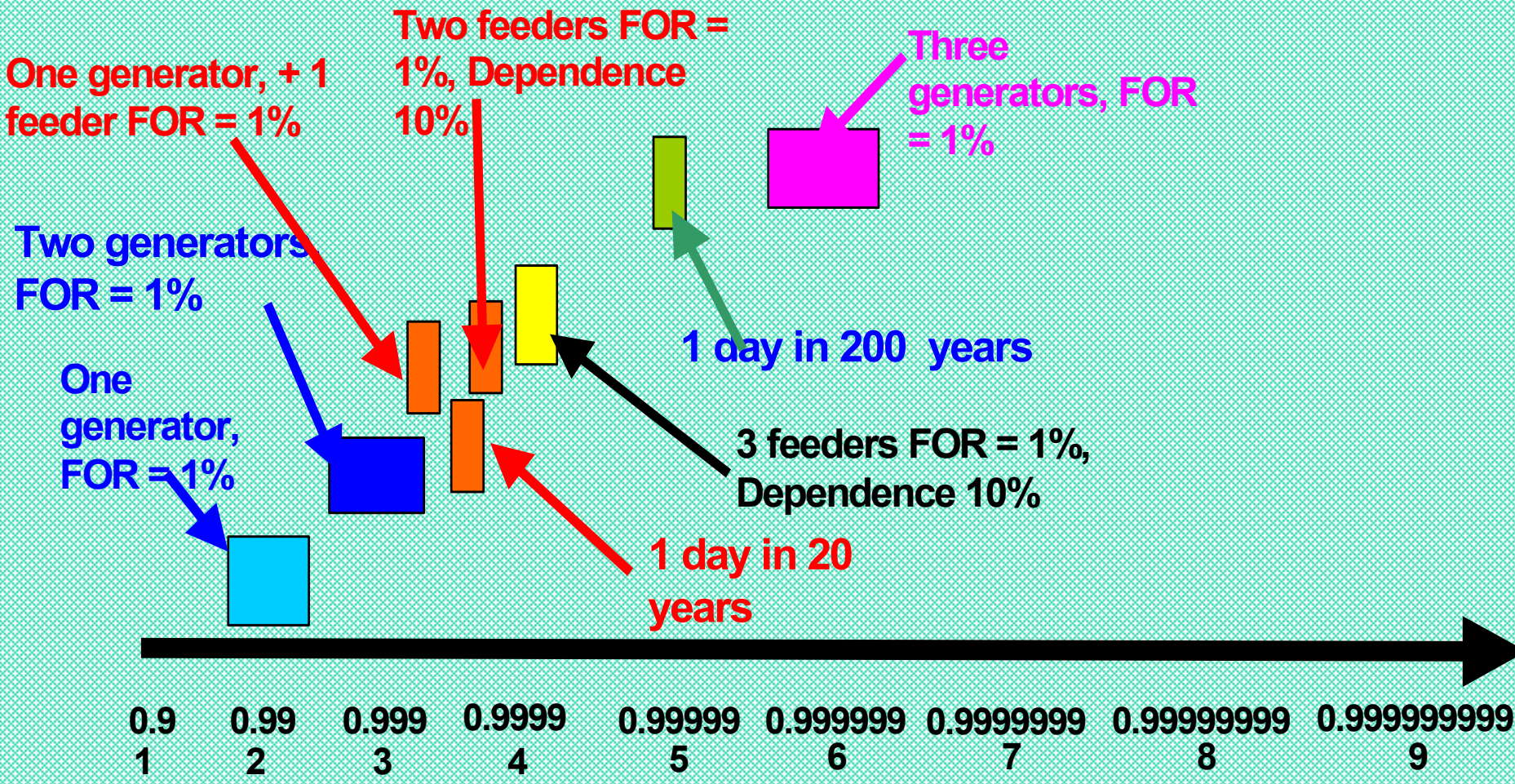


TWO FEEDERS    RELIABLE LOAD BUS

**The dependence of the sources will result in a much higher outage rate than  $(1-P_1)(1-P_2)$**



**The addition of feeders to improve reliability has a diminishing effect. For practical cases, use of more than three ‘independent’ feeders of 100% capacity is counterproductive.**



One generator, + 1 feeder FOR = 1%

Two feeders FOR = 1%, Dependence 10%

Three generators, FOR = 1%

Two generators FOR = 1%

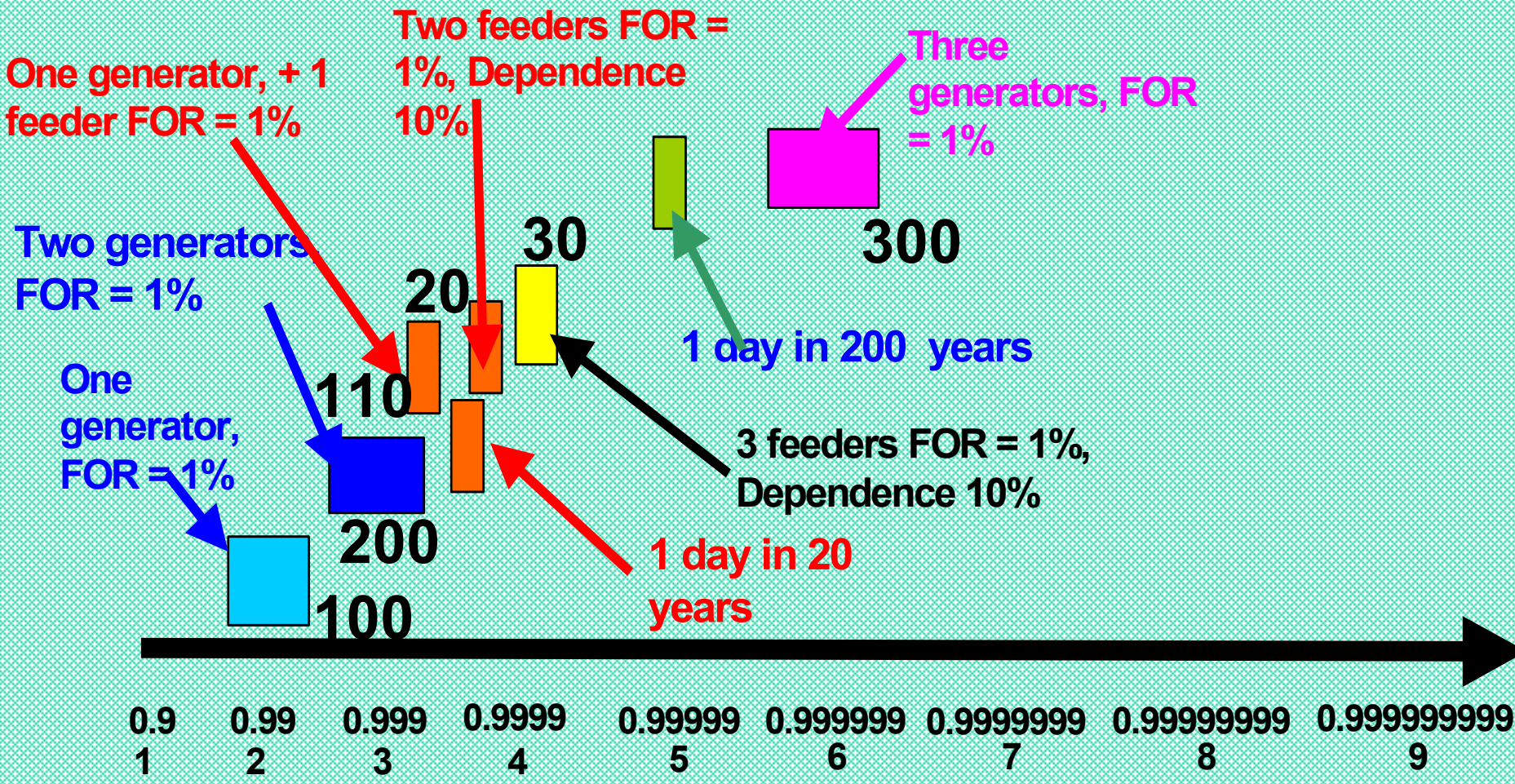
1 day in 200 years

One generator, FOR = 1%

3 feeders FOR = 1%, Dependence 10%

1 day in 20 years

0.9 0.99 0.999 0.9999 0.99999 0.999999 0.9999999 0.99999999 0.999999999  
 1 2 3 4 5 6 7 8 9



# **DISTRIBUTED GENERATION**

**FUEL CELLS**

**MICROTURBINES**

**DIESEL SETS**

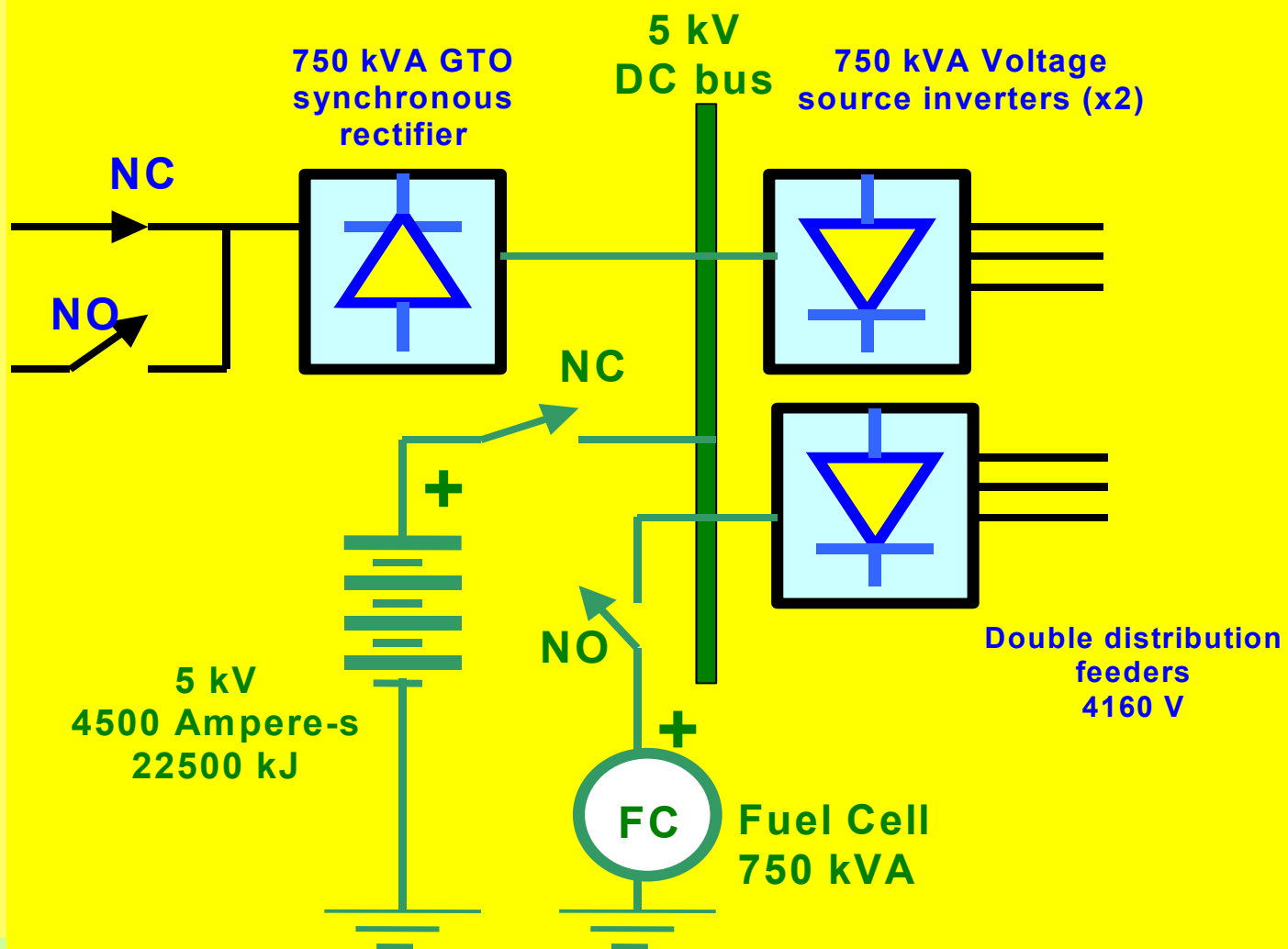
## ***MOTIVATION***

**RELIABILITY  
ENHANCEMENT**

**ENVIRONMENTAL  
ISSUES**

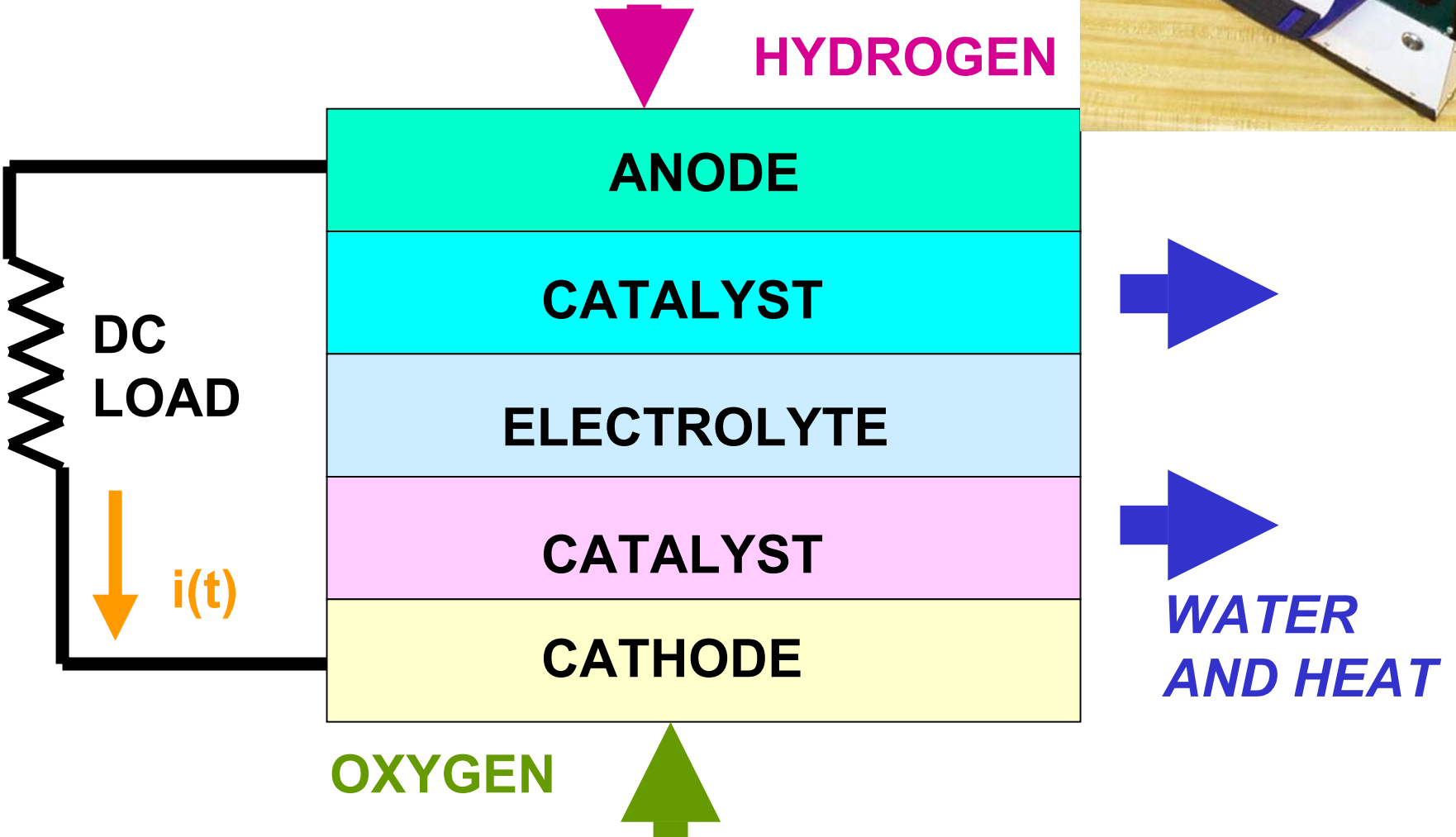
**TRANSMISSION  
CONGESTION**

**COGEN  
APPLICATIONS**



Many alternative generation sources have power electronic interfaces with the 60 Hz load bus. In some designs, the DC bus may be integrated with a battery energy storage system for seamless transfer of the load.

# FUEL CELLS



# FUEL CELLS

- **POTENTIAL HIGH EFFICIENCY**
- **SPECIAL APPLICATIONS FOR COGEN**
- **MOBILE (AUTO) AND SPACE APPLICATIONS**
- **A LOT OF PROPONENTS**
- **RELIEVES TRANSMISSION CONGESTION**
- **VERY HIGH COST**
- **POTENTIAL RELIABILITY PROBLEMS**
- **NOT GENERALLY COMMERCIALY AVAILABLE**
- **USES EXOTIC MATERIALS / CATALYSTS**
- **HIGH TEMPERATURE / SAFETY ISSUES**
- **GENERALLY NOT SUITED AT HIGH POWER LEVELS AND HIGH RELIABILITY APPLICATIONS**
- **FEW REALISTIC APPLICATIONS**
- **REQUIRES DC / AC CONVERSION**
- **DIFFICULT TO CONTROL**
- **WHERE IS ALL THIS FUEL GOING TO COME FROM?**
- **NO ECONOMY OF SCALE**
- **ENVIRONMENTAL ISSUES NOT WELL THOUGHT OUT**
- **NEEDS MORE RESEARCH / BREAKTHROUGHS**
- **LARGE SIZE**

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**PHOSPHORIC  
ACID 250 kVA  
FUEL CELL**

**PROTON EXCHANGE  
MEMBRANE FUEL CELL -  
7.5 kVA**



# MICROTURBINES

- **Low capacity, high speed units with electronic interface with 60 Hz bus**
- **Alternative fuel sources (e.g., biogas, gasifier, pyrolysis, fuels that have less than 10% of heat content compared to fossil fuels)**
- **Catalytic combustor to reduce nitrous oxide production**
- **Heat recovery**
- **Lower capacities -- e.g.,  
5 - 300 kVA**
- **High efficiency small units**



# MICROTURBINES

## Proposed application areas

- **Electric vehicles**
- **Capacity addition**
- **Stand alone power supplies**
- **Cogeneration / resource recovery**
- **Peak shaving**
- **High reliability applications,  
independent fuel source**

**The main grand challenges of achieving  $N$  nines reliability using DERs are:**

- **Development of strategies for adding DERs**
- **Development of analytical procedures for systems of multiple local controls, and the coordination of those controls**
- **The complete analysis of normal and abnormal operating modes of DERs**
- **The resolution of safety issues relating to energization of distribution buses at the load end**
- **The rethinking of protective relaying issues for systems with multiple DERs**
- **The advancement of agent technologies for systems reliability enhancement, and the resolution of issues of power electronic controller compatibility**
- **Analysis of dependence of fuel sources**

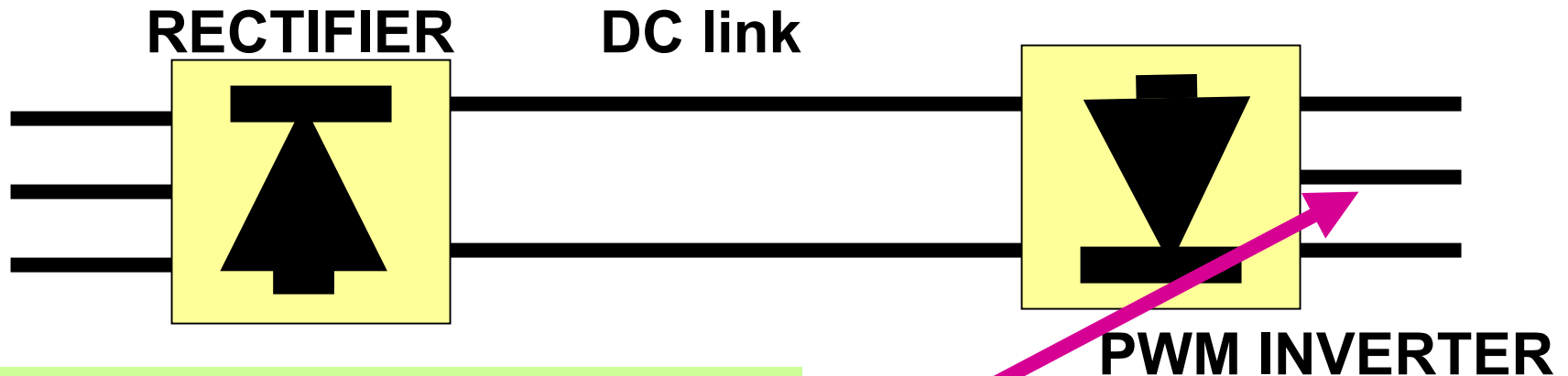
# **ELECTRONIC SOLUTIONS FOR POWER CONDITIONING**

## **Shunt positioning in system to inject current**

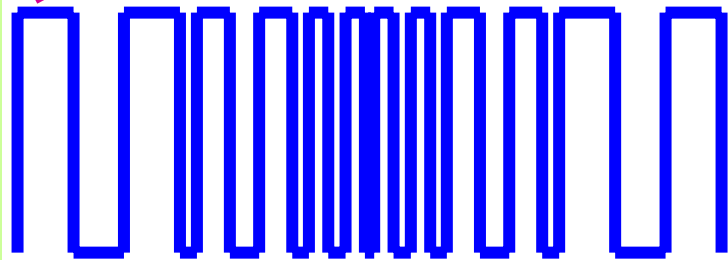
**Inject series voltage  
for phase control /  
exchange energy  
between phases**

**Back - to - back  
rectifier / DC link /  
inverter**

# AC - AC Converter Technologies



THE UNIFIED POWER FLOW CONTROLLER UTILIZES IGBT TECHNOLOGY TO GENERATE PWM SIGNALS OF CONTROLLABLE MAGNITUDE / PHASE. THIS EFFECTIVELY CONTROLS THE ACTIVE POWER FLOW WHEN INJECTED AS A SERIES VOLTAGE



# THE UPFC

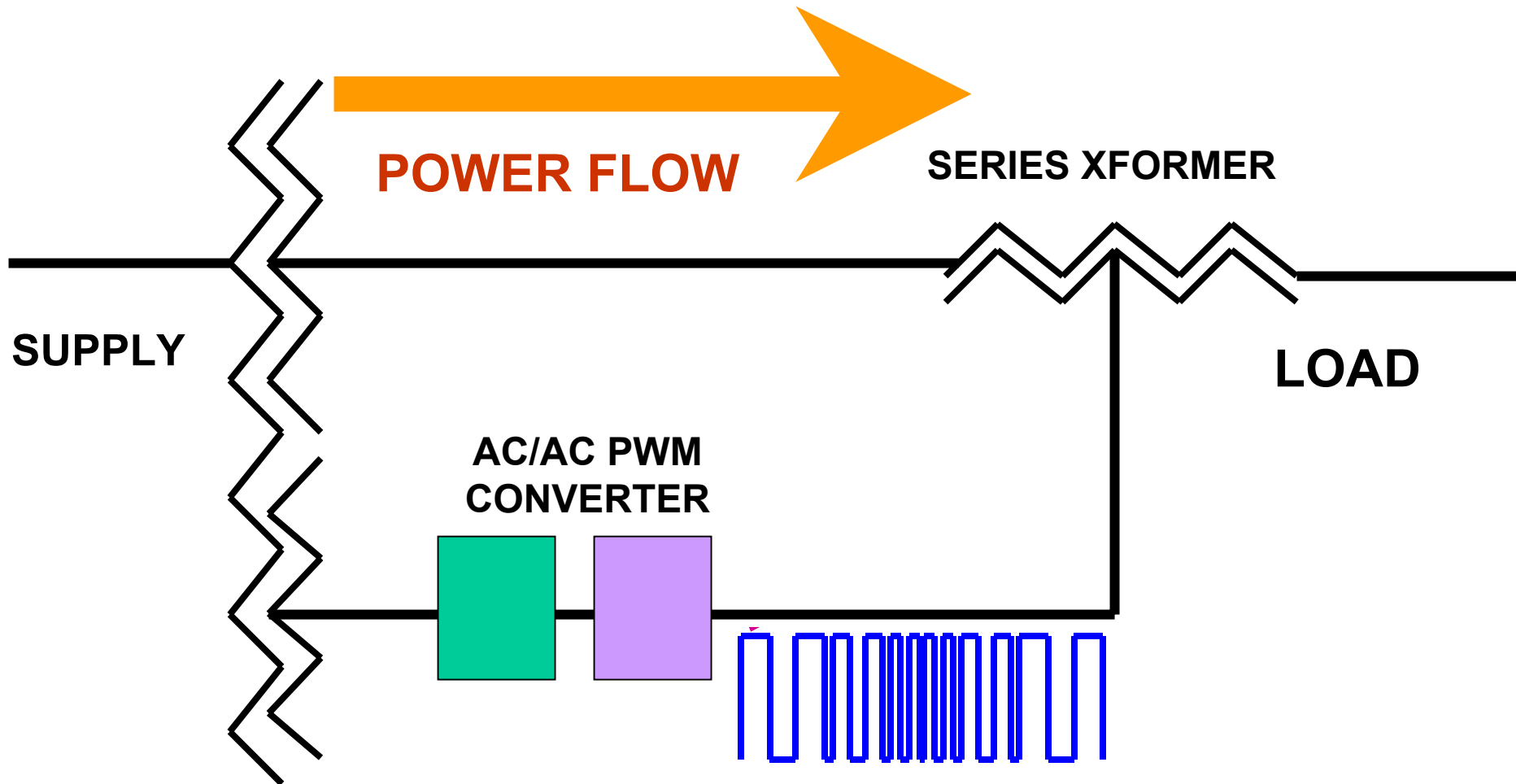
- 1/4 cycle response time
- Very low DC link power
- Can be protected by crowbaring supply
- Individual phase control / exchange energy between phases
- Controls slow variations in supply voltage
- The distribution version (DVR) can improve supply power factor and power quality
- For the distribution version, potential elimination of vulnerable load problems
- For UPFC, can reduce transmission congestion as well as improve dynamic response
- **Cost is high**
- **Local solution (?)**
- **Controls are tricky, coordination of controls**
- **Solution of diversity of ownership problems**
- **Relatively low power injected**
- **Limited experience in applications**
- **Reliability issues**

# THE UPFC FACTS DEVICE as a transmission element

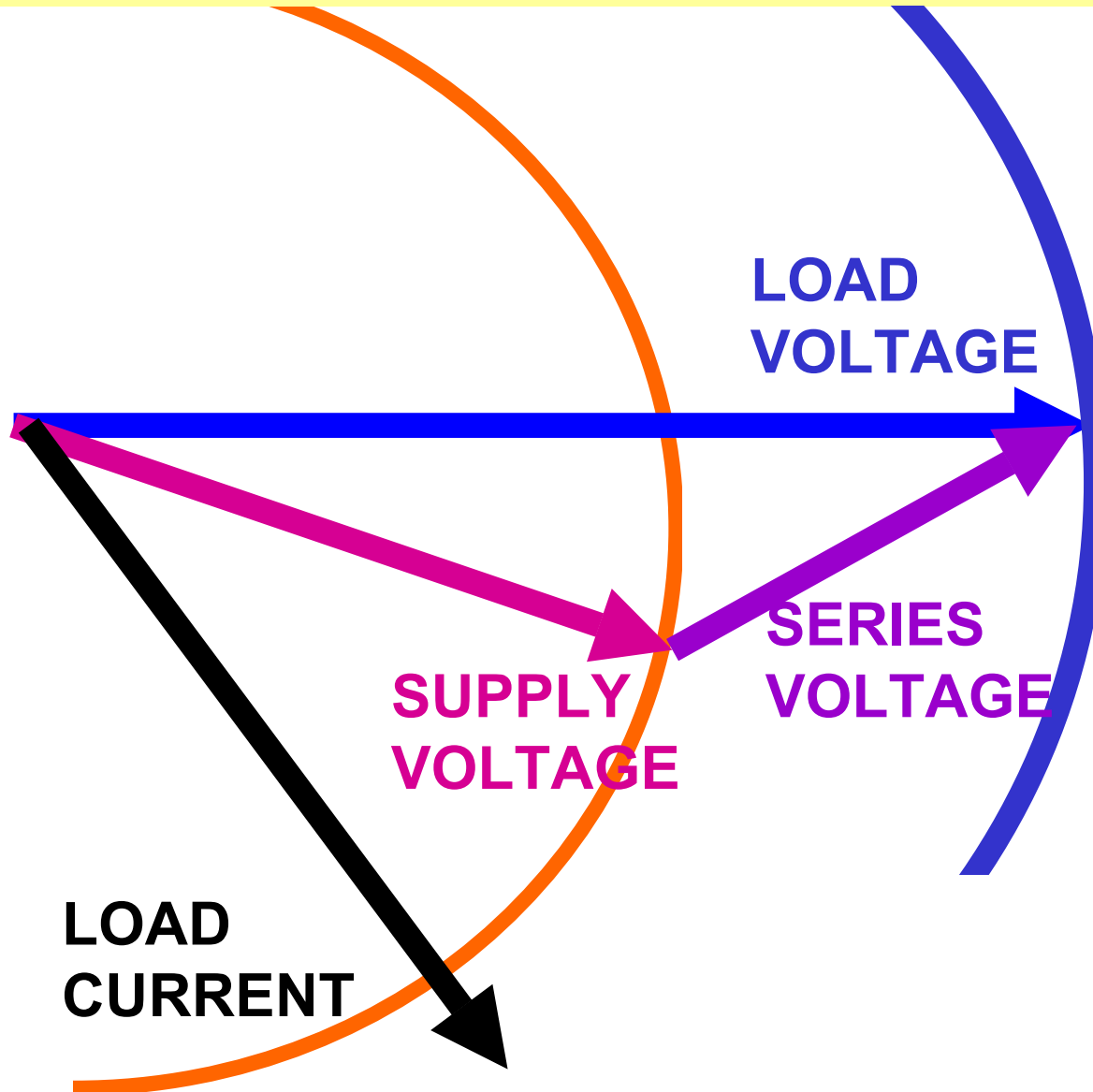
- **ALLOWS CONTROL OF POWER FLOW**
- **CONDITIONS POWER**
- **CONTROLS CAN BE COORDINATED TO ENHANCE DYNAMIC STABILITY**
- **CAN SELL TRANSMISSION CAPACITY**
- **REACTIVE POWER SUPPORT**
- **CAN REPLACE SPECIAL PROTECTION SCHEMES WITHOUT THE NEED OF GENERATOR RESYNCHRONIZATION**
- **COST**
- **LITTLE EXPERIENCE IN ACTUAL USE**
- **RELIABILITY ISSUES**
- **PQ IMPLICATIONS**



# THE UPFC and DVR



# THE UPFC and DVR





# GRAND CHALLENGES

- **Modeling and controlling energy source dependence**
- **Resolving reliability and control issues for DERs**
- **Evolution of power electronic topologies for high reliability applications**
- **Control of the cost/benefit ratio for alternative high reliability designs**
- **Agent design for DERs and agent communications issues**
- **Study of typical global system response due to local controls**
- **Controllability of selected system modes**
- **'Adding another 9'**