Synchronous Generators and their applications in power system

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TSU DEGREE PROGRAMS OFFERED

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  - offers a concentration in Computer Engineering - Fall 1997
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- **M.S. CISE** - Computer and Information Systems Engineering (1997) integrates systems engineering, computer hardware & software

- **Ph.D. in CISE - Compute Communication and Networks, Control System and Signal Processing, Robotics and Computer Integrated Manufacturing (-2001)**

Sources of energy

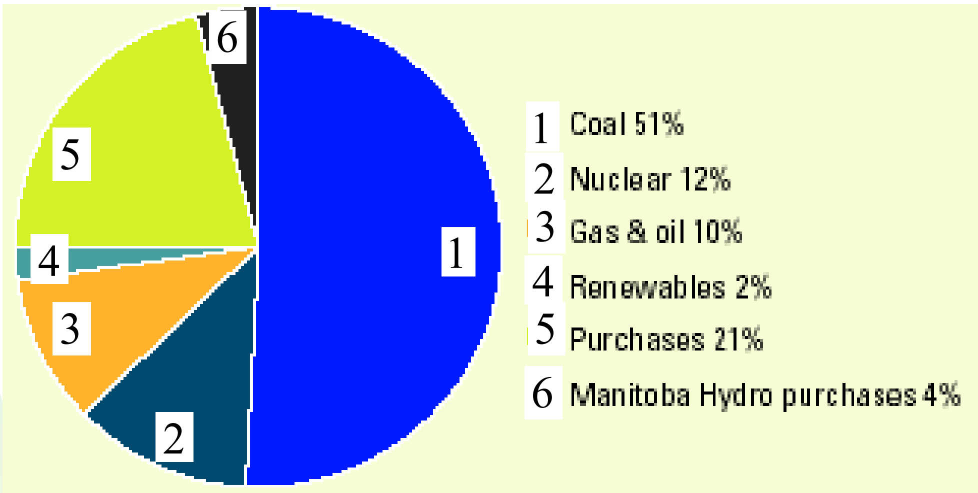


Fig. 3-16 Resource mix at XcelEnergy [14].

Rankine Thermodynamic Cycle in Coal Plants

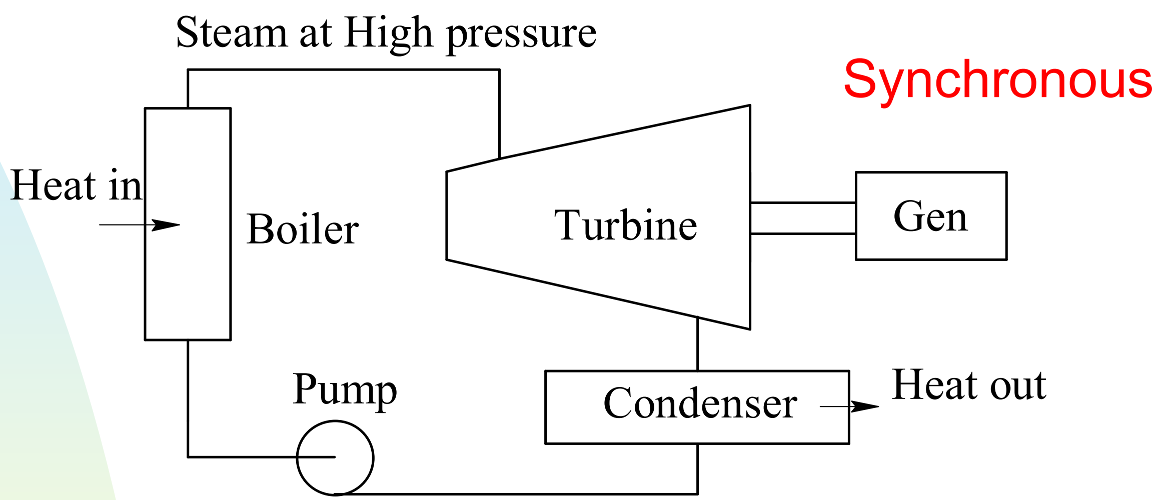


Fig. 3-4 Rankine thermodynamic cycle in coal-fired power plants.

Visit the following website for Power Plant Animations:

http://www.cf.missouri.edu/energy/?fun=1&flash=ppmap

Efficiency 38% maximum

Brayton Cycle in Gas Turbines

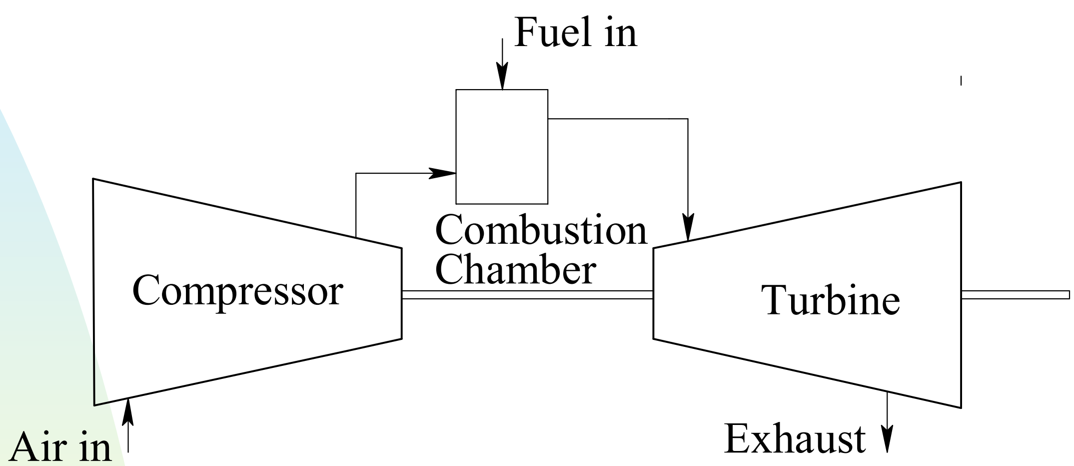


Fig. 3-5 Brayton thermodynamic cycle in natural-gas power plants.

Synchronous generator

Non-salient pole, high speed generators

maximum efficiency 35% for single cycle, 55-60% for combined cycle

Hydro Power Generation

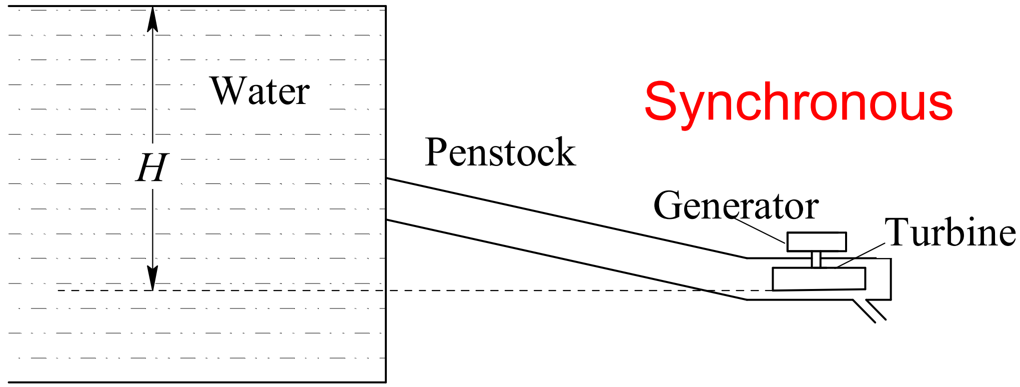
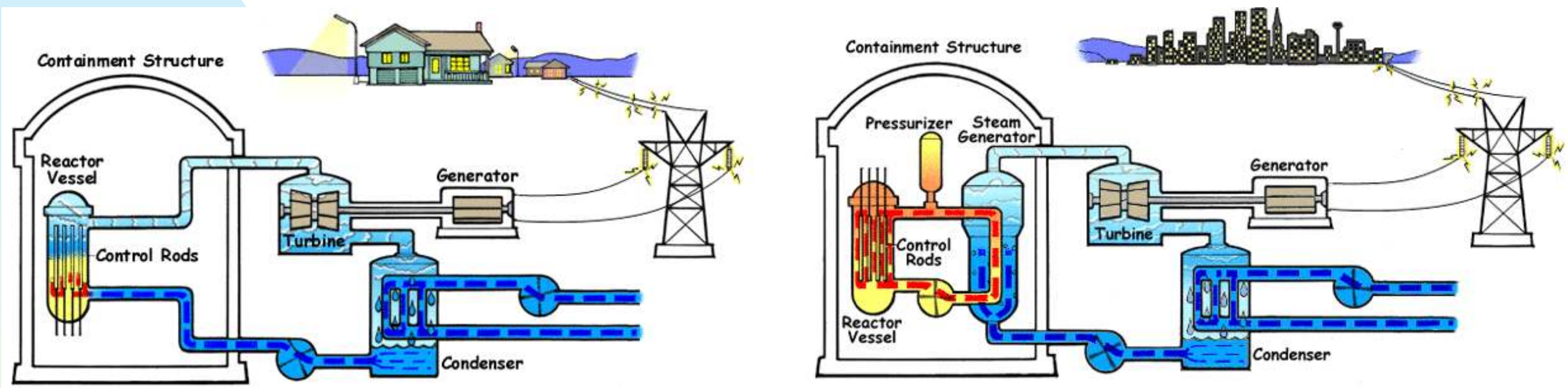


Fig. 3-3 Hydro power (Source: www.bpa.gov).

Turbine efficiency 93%

Slow speed, salient pole, larger size generators

Nuclear Power Plant Types



(*a*) (*b*)

Fig. 3-6 (a) BWR and (b) PWR reactors [5].

Visit the following websites for Nuclear Power Plant Animations:

PWR: http://www.nrc.gov/reading-rm/basic-ref/students/animated-pwr.html

BWR: http://www.nrc.gov/reading-rm/basic-ref/students/animated-bwr.html

Wind Generation using an Induction Generator Connected Directly to the AC Grid

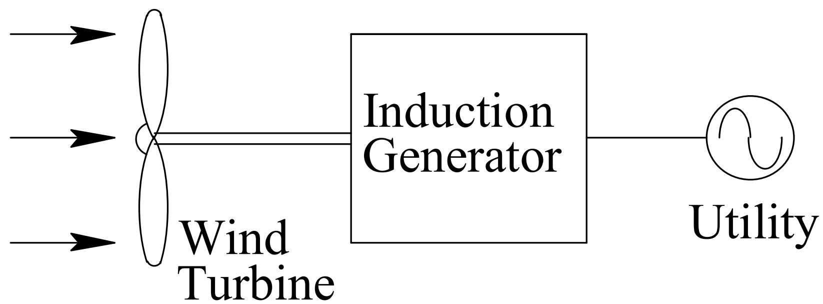


Fig. 3-9 Induction generator directly connected to the grid [8].

Coefficient of Performance

$$P_w = C_p \left(\frac{1}{2} \rho A V^3 \right)$$

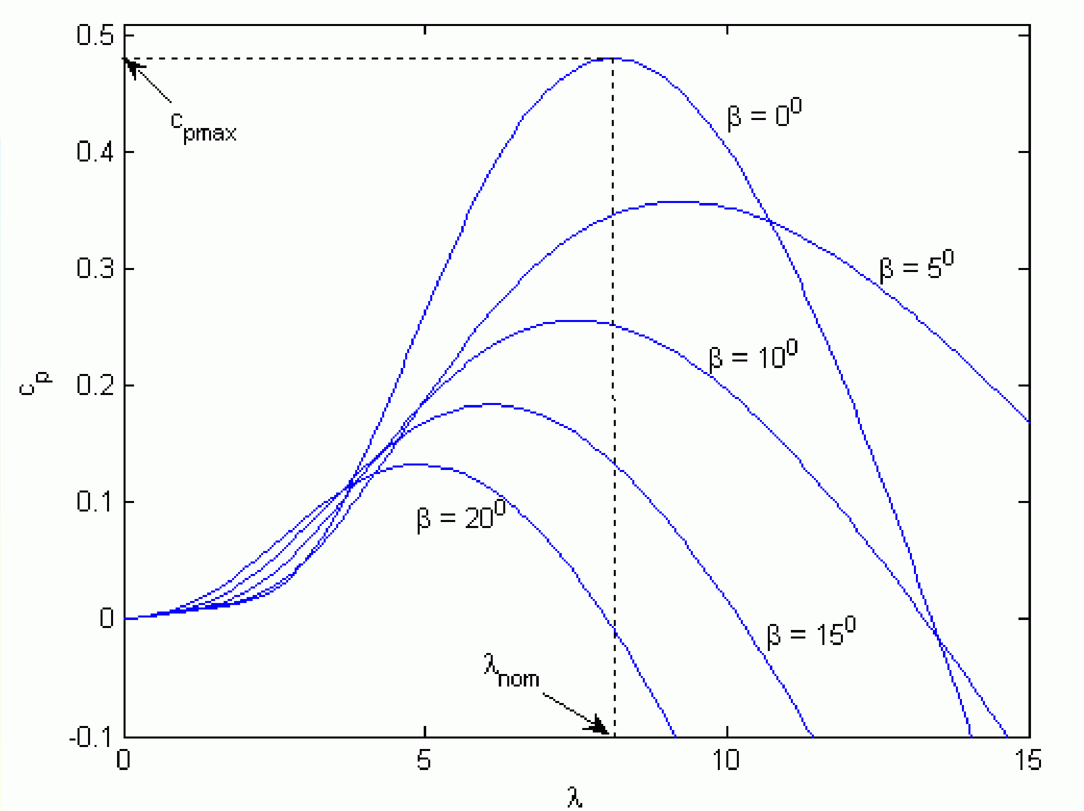


Fig. 3-8 c_p as a function of λ [7]; these would vary based on the turbine design.

Wind Generation using a Doubly-Fed Induction Generator

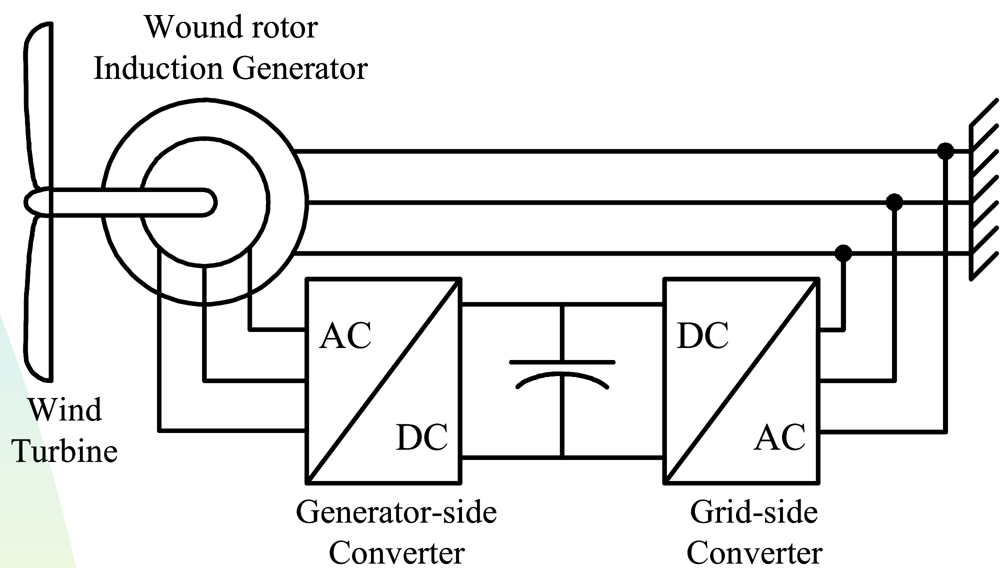


Fig. 3-10 Doubly-fed, wound-rotor induction generator [9].

Wind Generation using an AC Generator Connected through Power Electronics

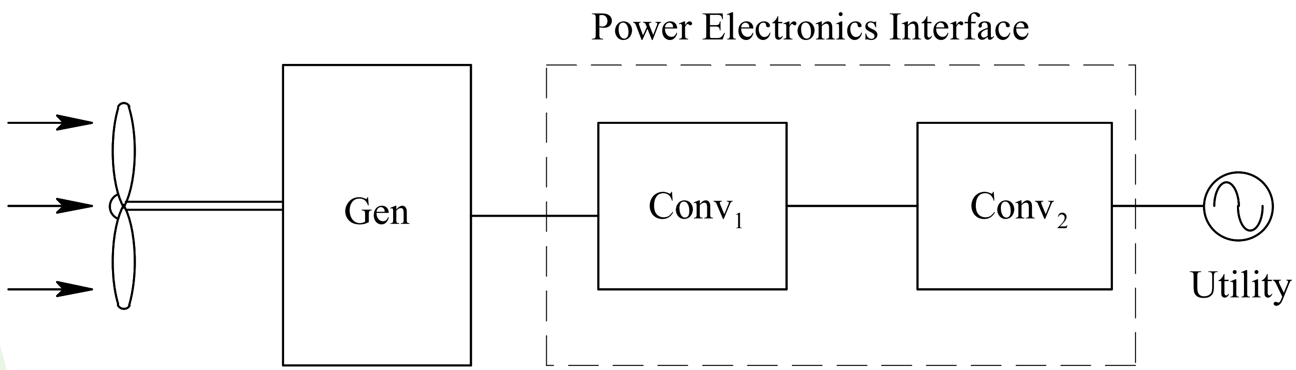


Fig. 3-11 Power Electronics connected generator [10].

Variable voltage and variable speed generations

Photovoltaics

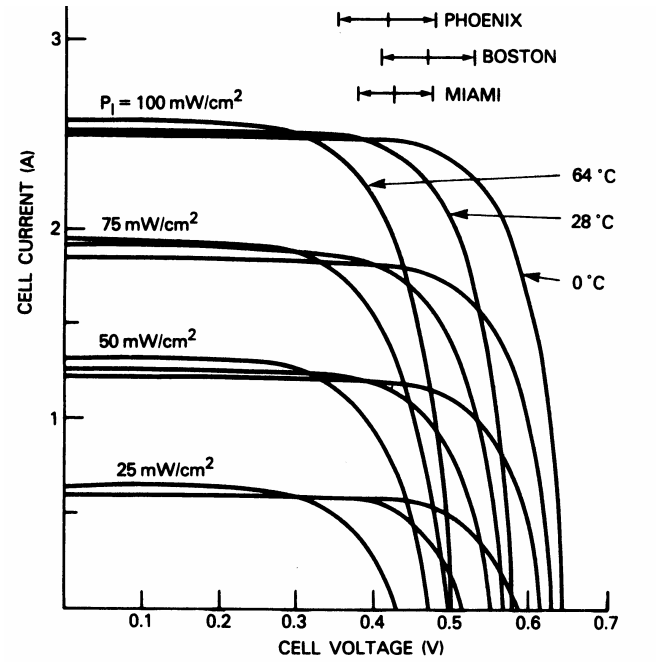


Fig. 3-12 PV cell characteristics [11].

- Efficiency ranges from 5% to 18% depending upon materials used - not competitive

Interfacing PV with AC Grid

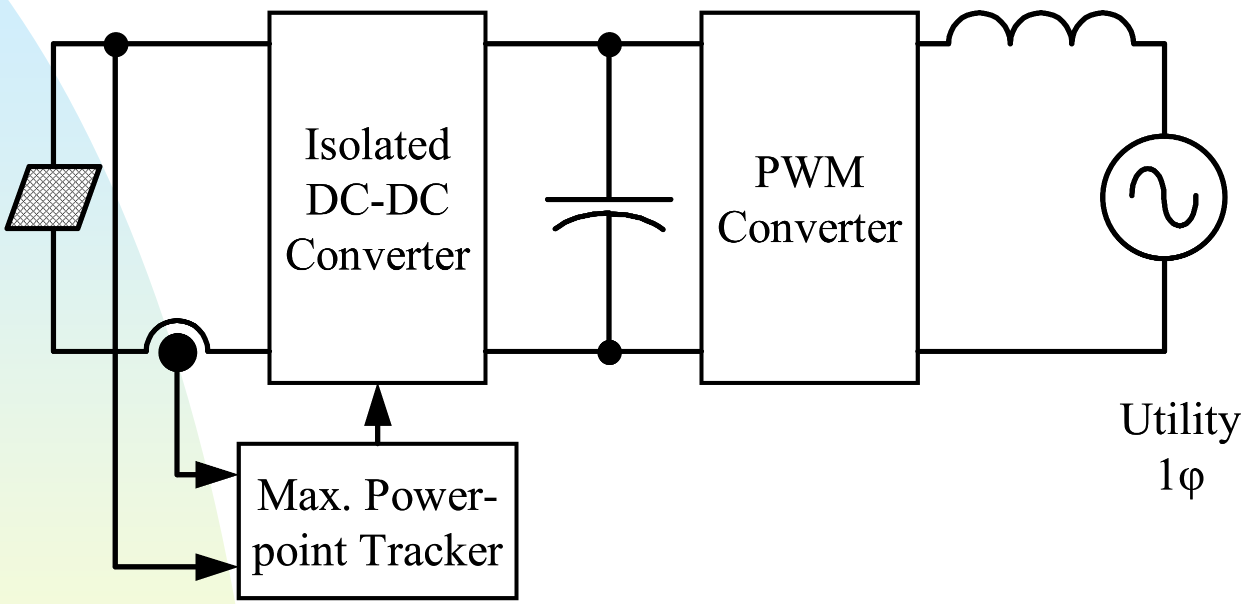


Fig. 3-13 Photovoltaic systems.

Fuel Cells

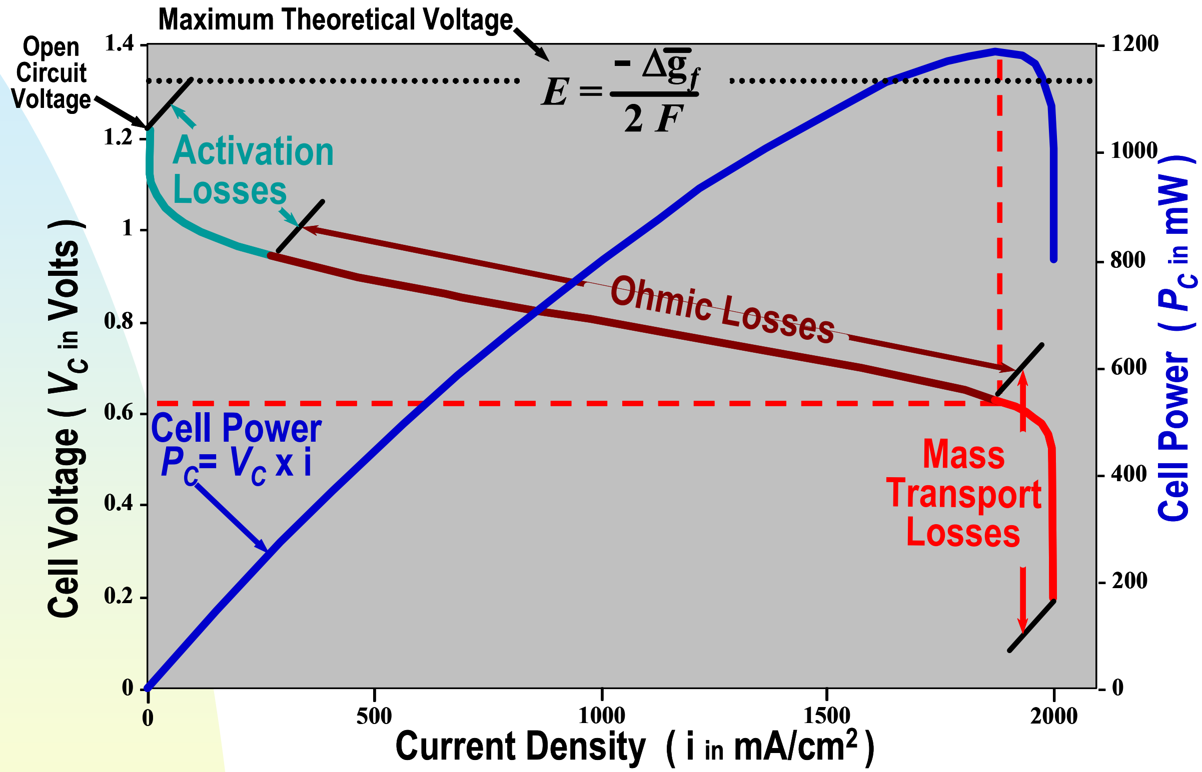


Fig. 3-14 Fuel cell *v-i* relationship and cell power [12].

- Not yet commercially competitive

Application of Synchronous Generators

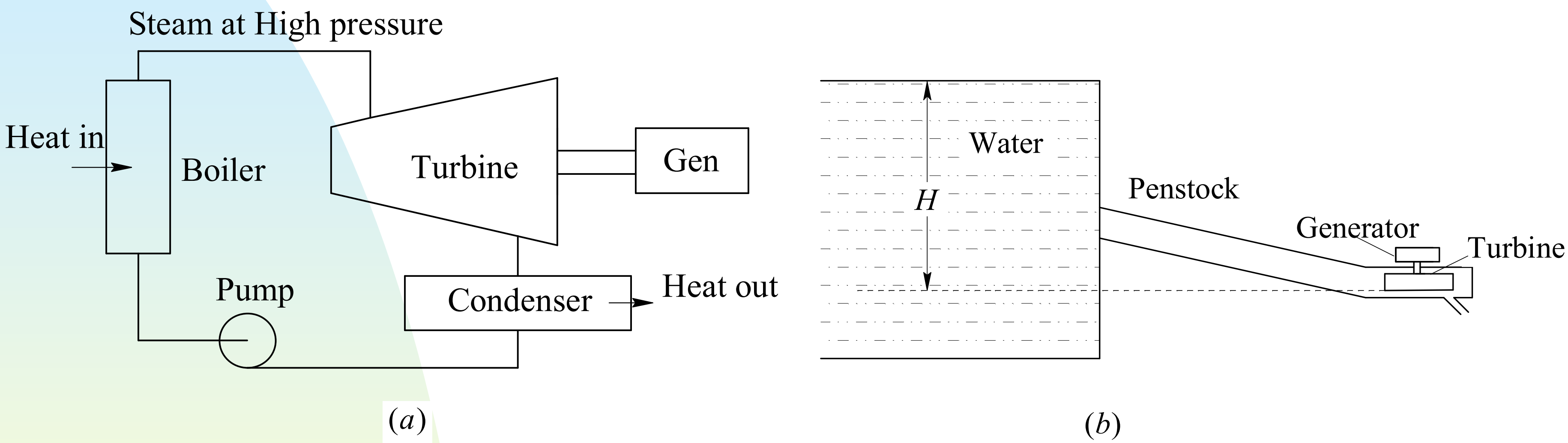


Fig. 9-1 Synchronous generators driven by (a) steam turbines, and (b) hydraulic turbines.

Synchronous Generators

Maintain synchronism

Reactive Power flow control

Power System Stability

Short Circuit Control

Cross-section of Synchronous Generators

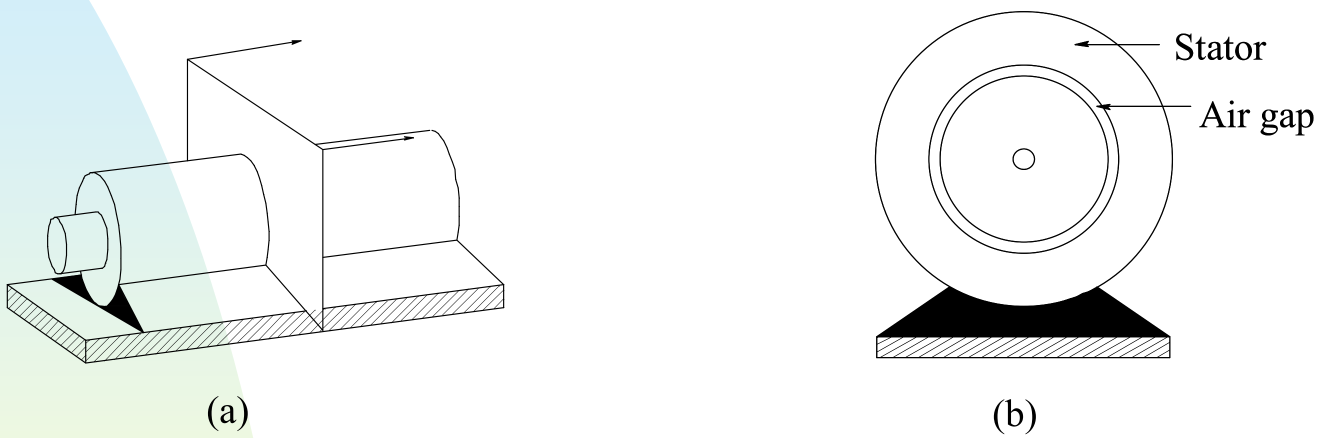


Fig. 9-2 Machine cross-section.

Non-salient pole alternators for high speeds

Synchronous Generator Structure

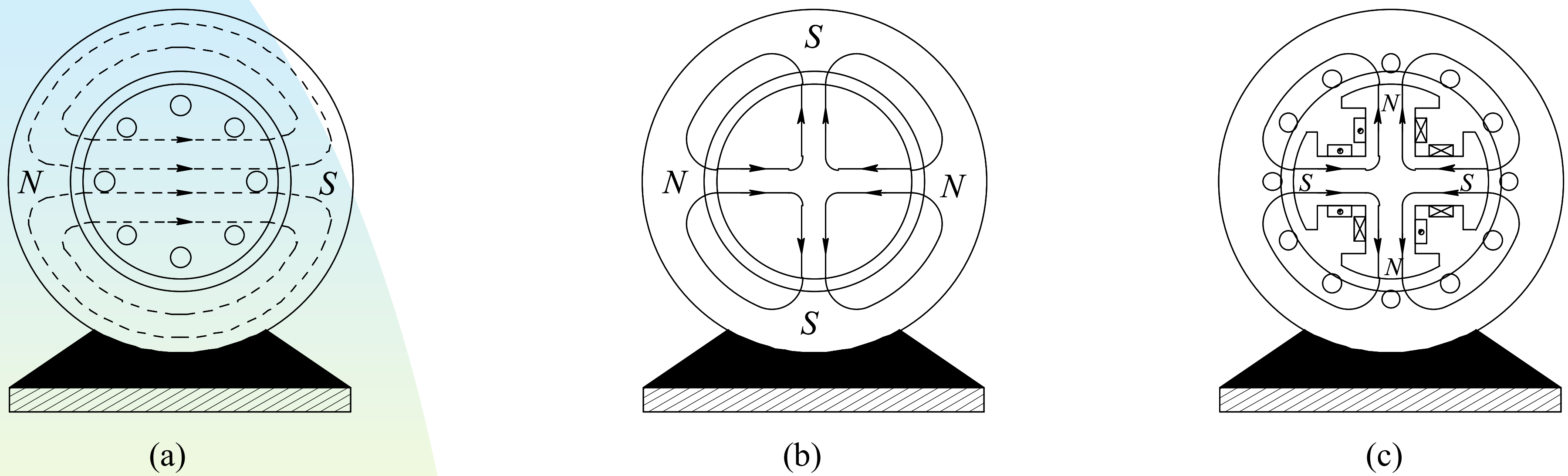


Fig. 9-3 Machine structure.

Salient pole generators for slow speeds

Sinusoidally-Distributed Windings

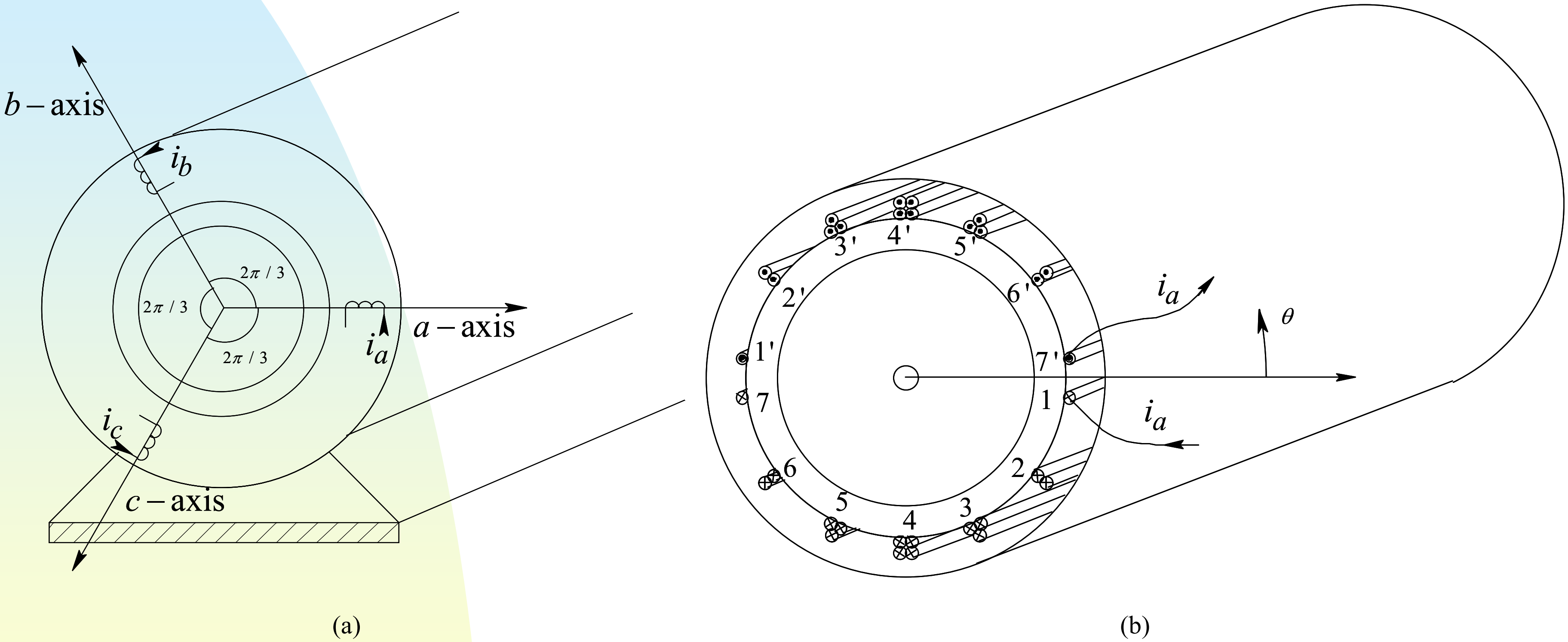


Fig. 9-4 Three phase windings on the stator.

Synchronous Generator Rotor Field

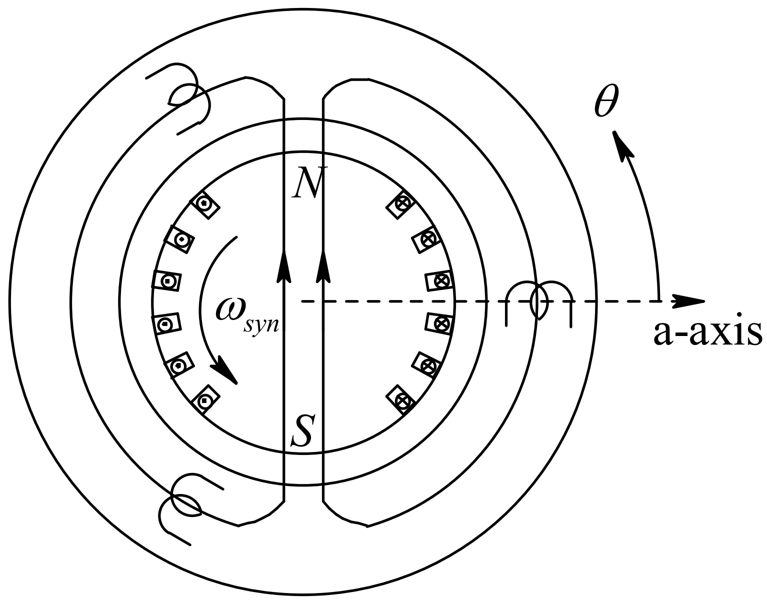


Fig. 9-6 Field winding on the rotor that is supplied by a dc current I_f.

Voltage induced in the Stator Phase due to Rotating Rotor Field

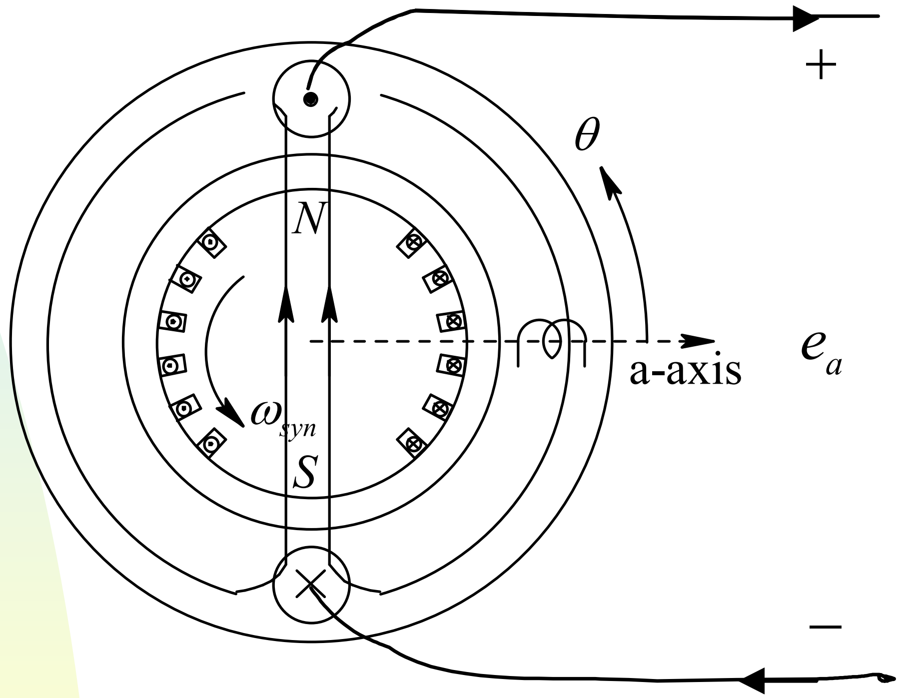


Fig. 9-7 Current direction and voltage polarities; the rotor position shown induces maximum e_a.

Plot of time-varying Flux and Voltage

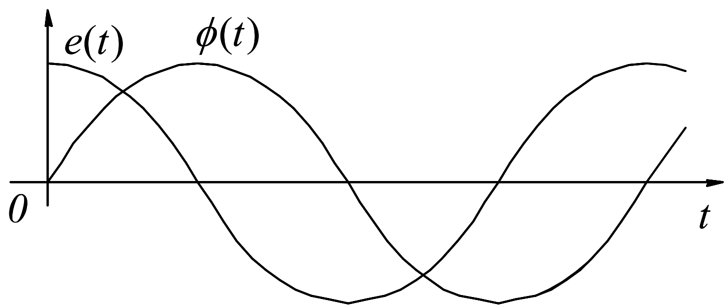


Fig. 2-27 Example 2-11.

$$emf = -\frac{Nd\phi}{dt}$$

Armature Reaction Due to Three Stator Currents

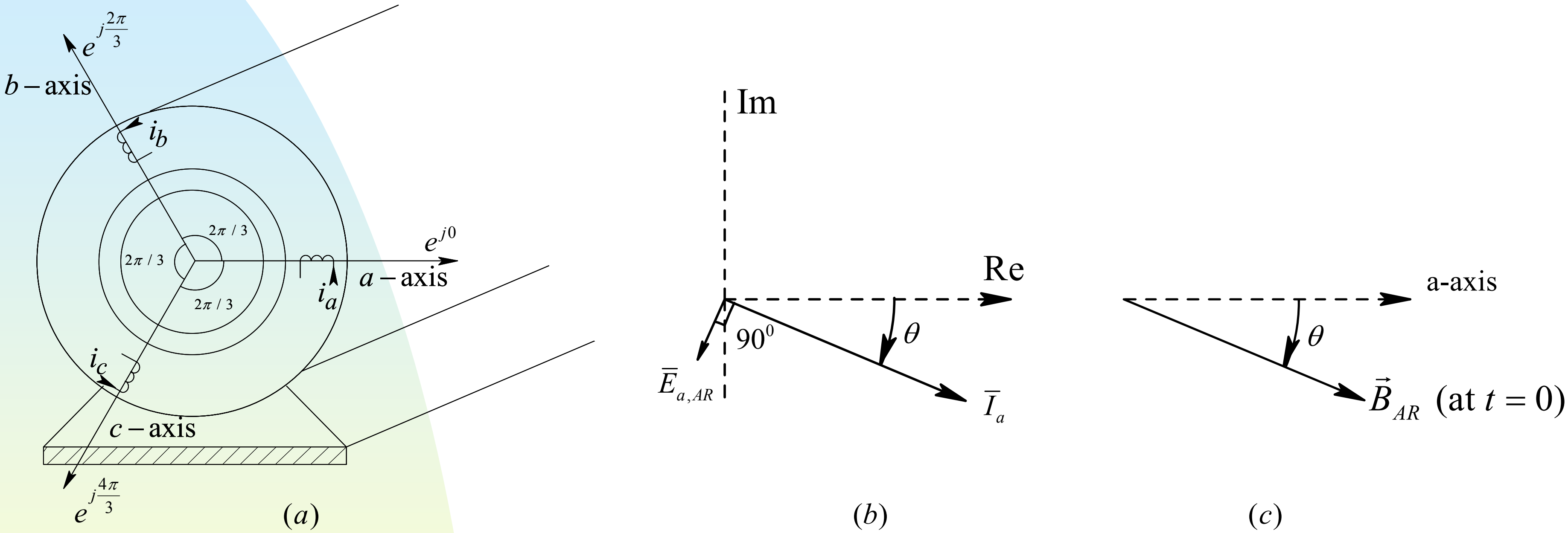


Fig. 9-9 Armature reaction due to phase currents.

Emf = - (rate of change of flux linkage)

Combined induced emf due to filed flux and armature reaction

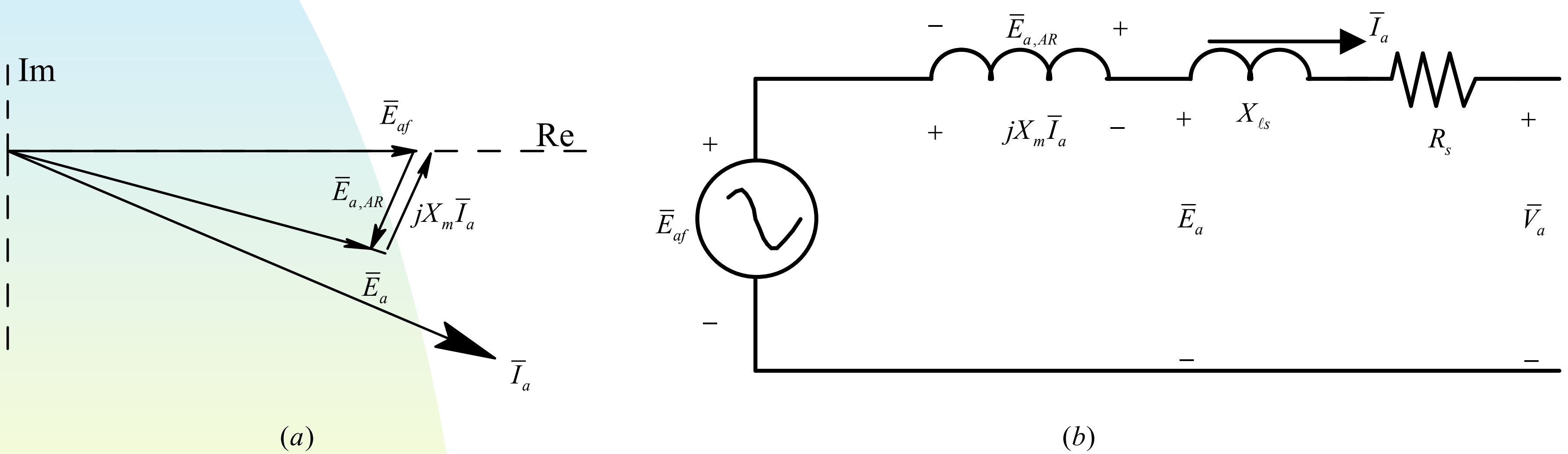


Fig. 9-10 Phasor diagram and per-phase equivalent circuit.

One-Machine Infinite-Bus System

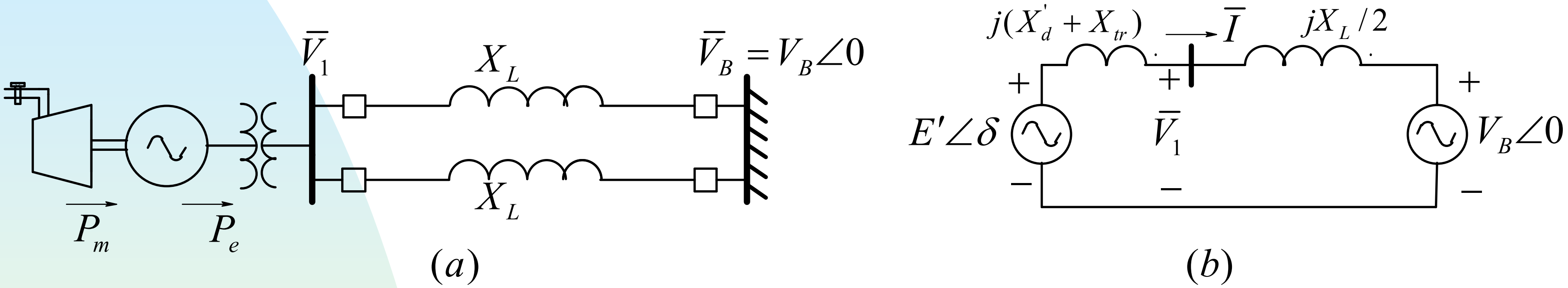


Fig. 11-1 Simple one-generator system connected to an infinite bus.

A Radial System

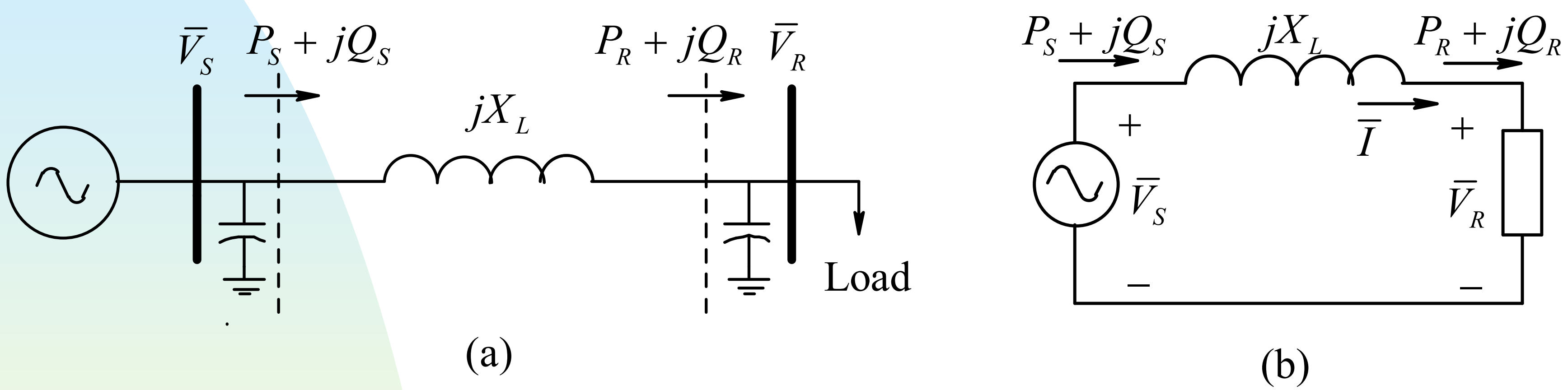


Fig. 10-1 A radial system.

Power Out as a function of rotor Angle and power stability

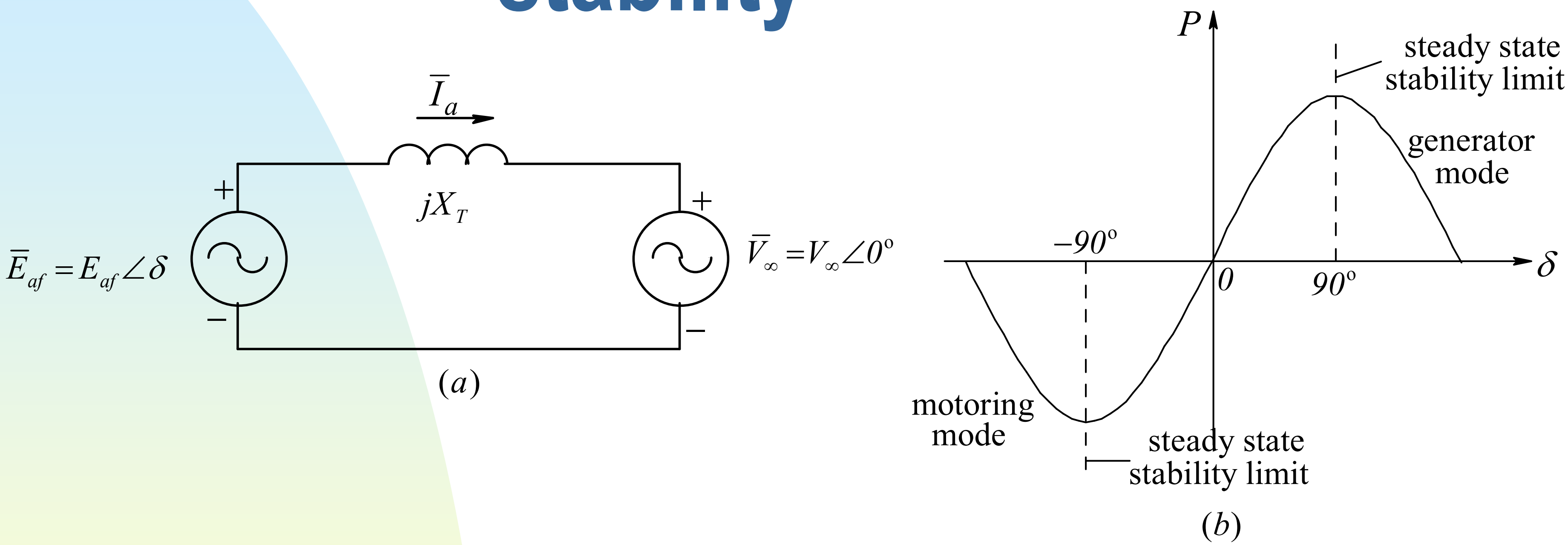


Fig. 9-11 Power output and synchronism.

Power Flow in AC Systems

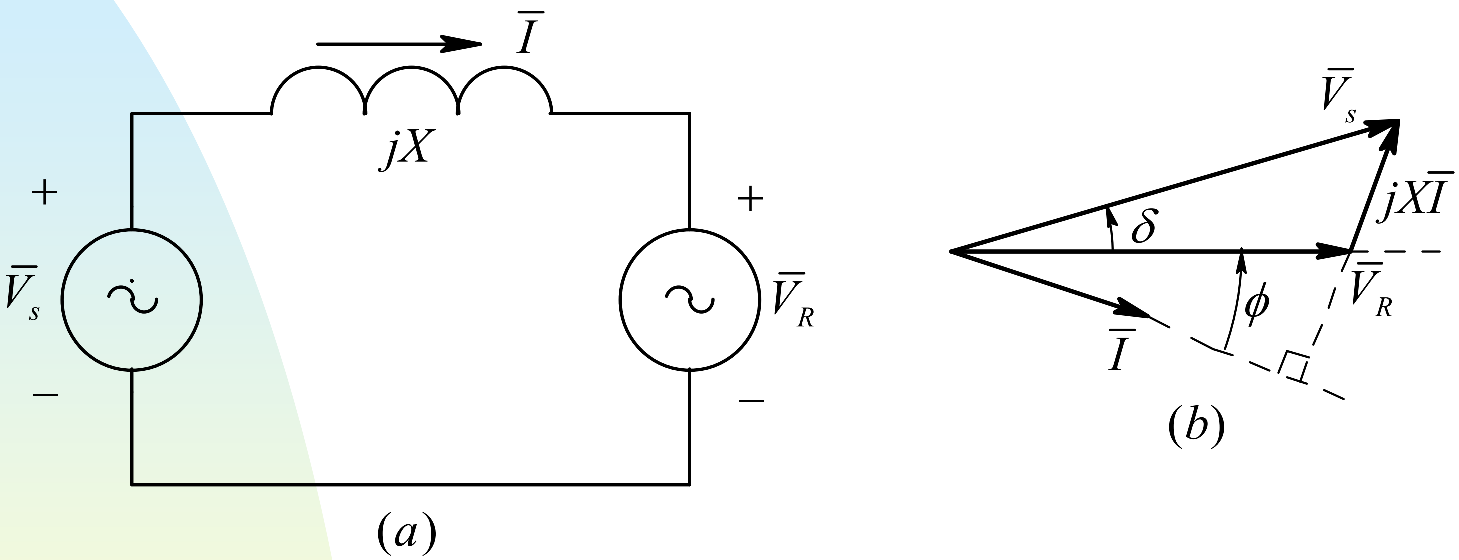


Fig. 2-17 Power transfer between two ac systems.

$$Q_R = \frac{V_S V_R \cos\delta - V_R^2}{X}$$

Steady State Stability Limit

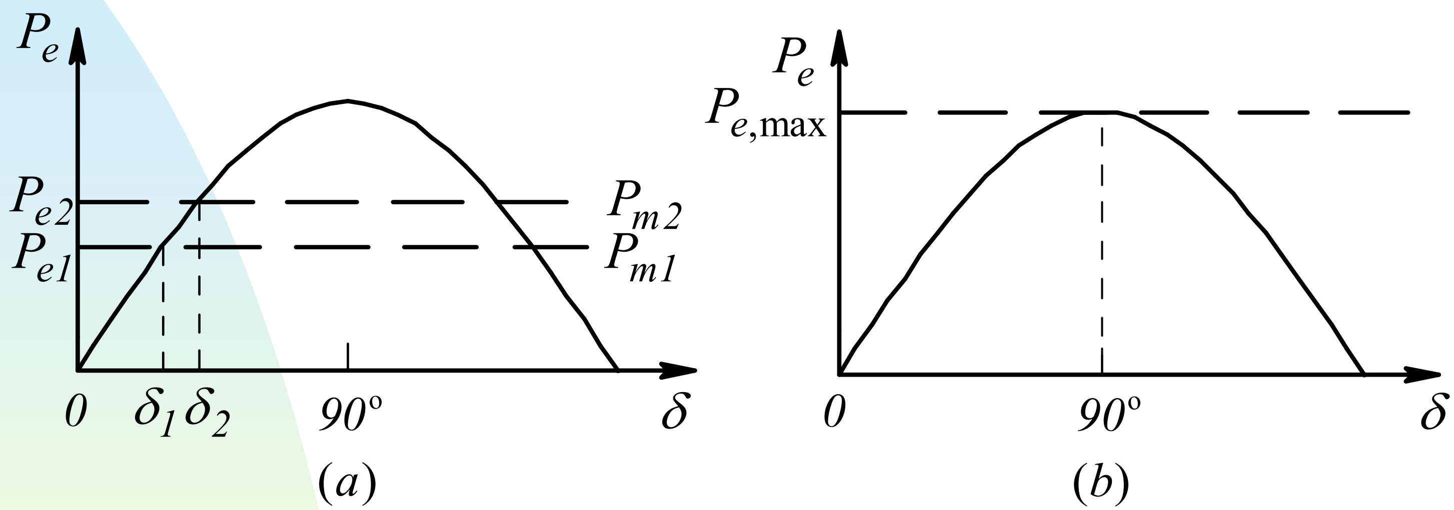


Fig. 9-12 Steady state stability limit.

$$P_R = \frac{V_S V_R \sin\delta}{X} \, watts$$

$$Q_R = \frac{V_S V_R \cos\delta - V_R^2}{X} \, \text{var}$$

Power-Angle Characteristics

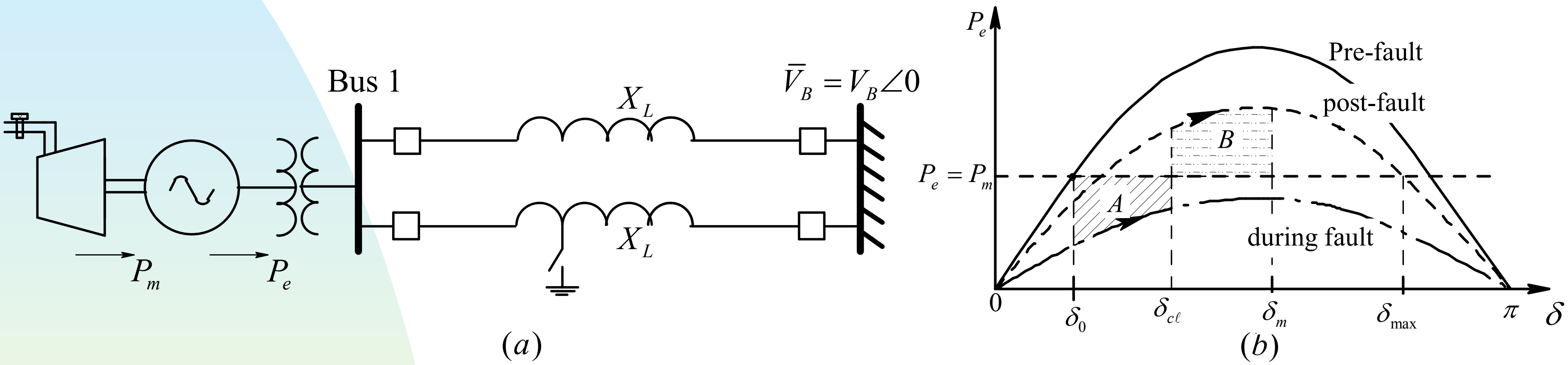


Fig. 11-4 Fault on one of the transmission lines.

Power-Angle Characteristic in One-Machine Infinite-Bus System

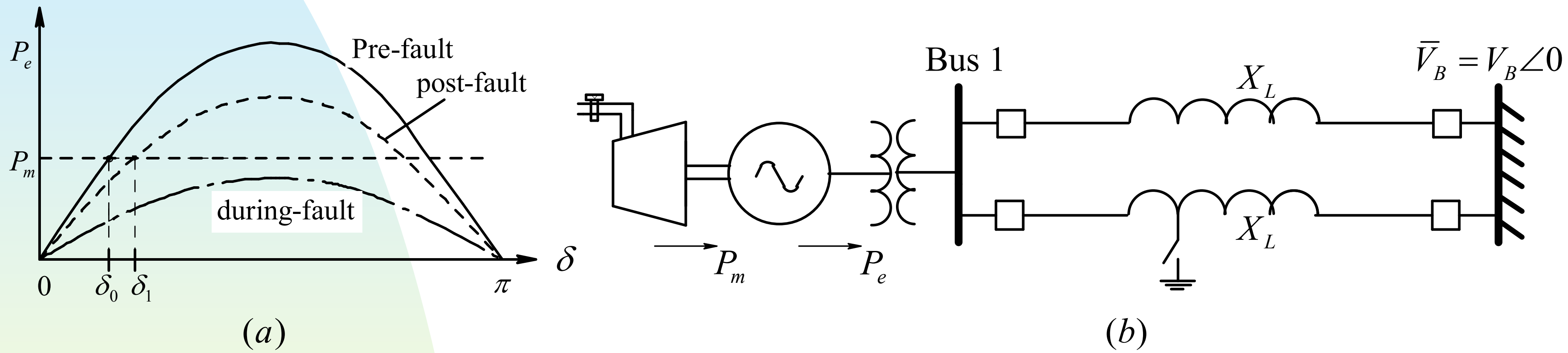


Fig. 11-2 Power-angle characteristics.

Critical Clearing Angle using Equal-Area Criterion

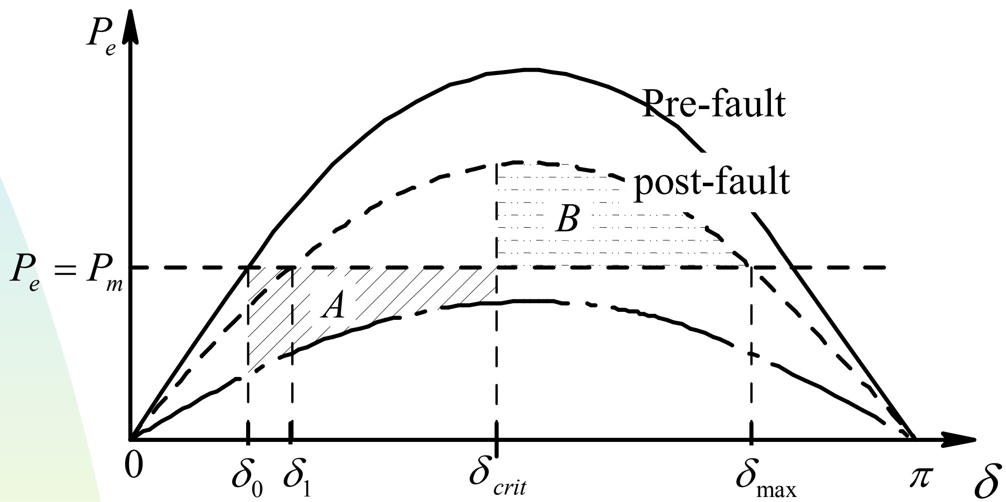


Fig. 11-6 Critical clearing angle.

Reactive Power Control by Field Excitation

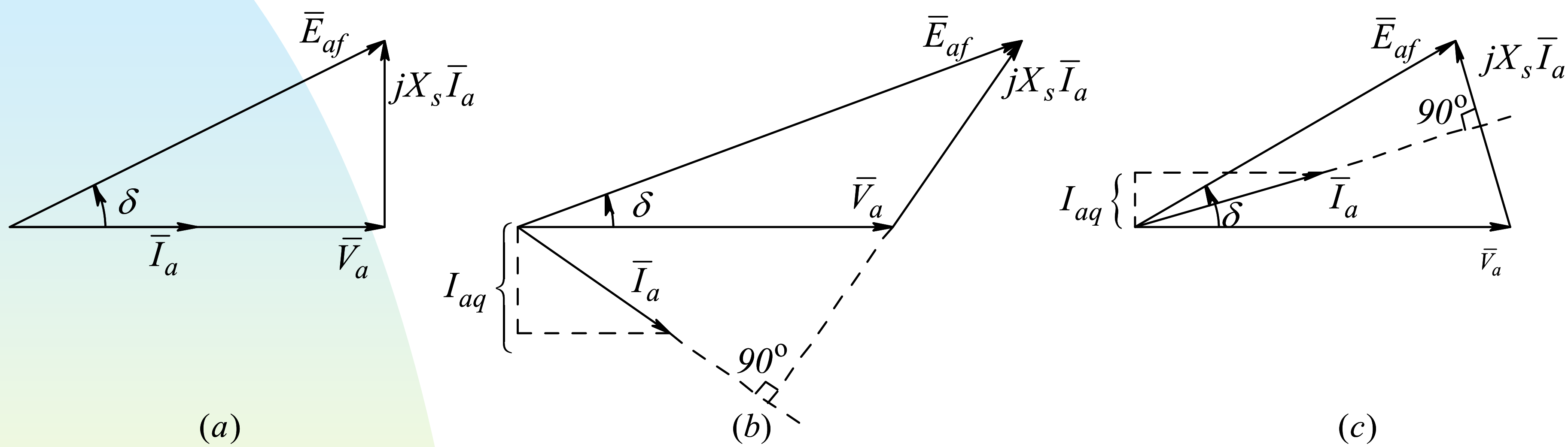


Fig. 9-13 Excitation control to supply reactive power.

Synchronous Condenser

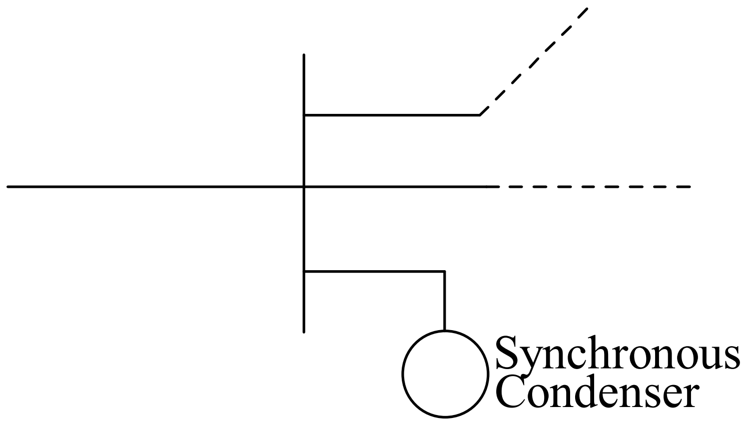


Fig. 9-14 Synchronous Condenser.

Automatic Voltage Regulation (AVR)

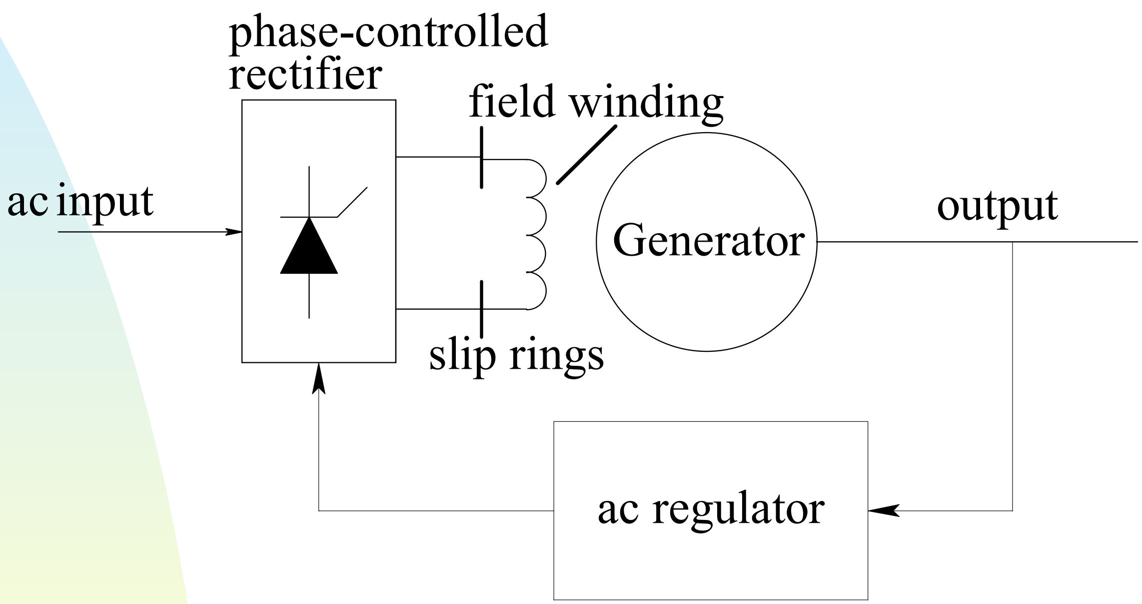


Fig. 9-15 Field exciter for automatic voltage regulation (AVR).

Short-Circuit Current

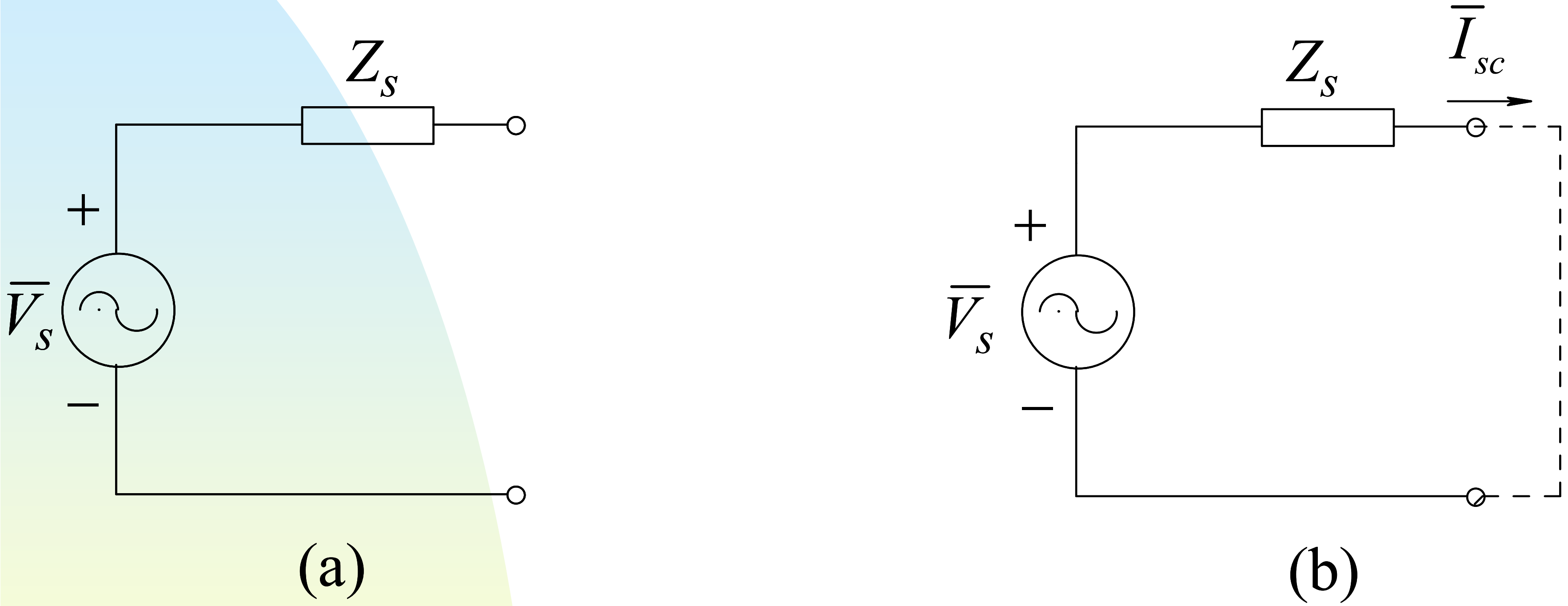


Figure 8-18 (a) Utility Supply, (b) Short-Circuit Current.

Armature Reaction Flux in Steady State Leading to Synchronous Reactance

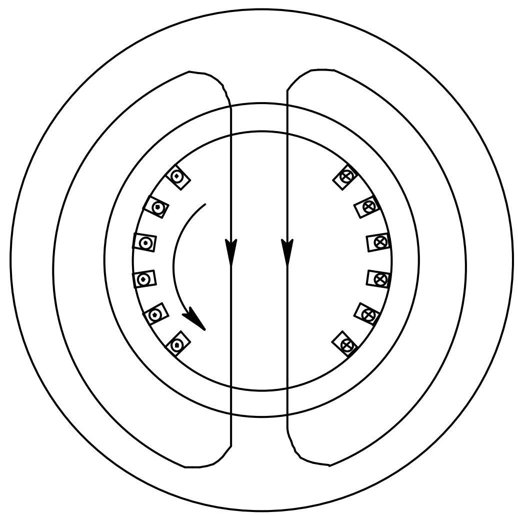


Fig. 9-16 Armature reaction flux in steady state.

Simulation of a Short-Circuit Assuming a Constant-Flux Model

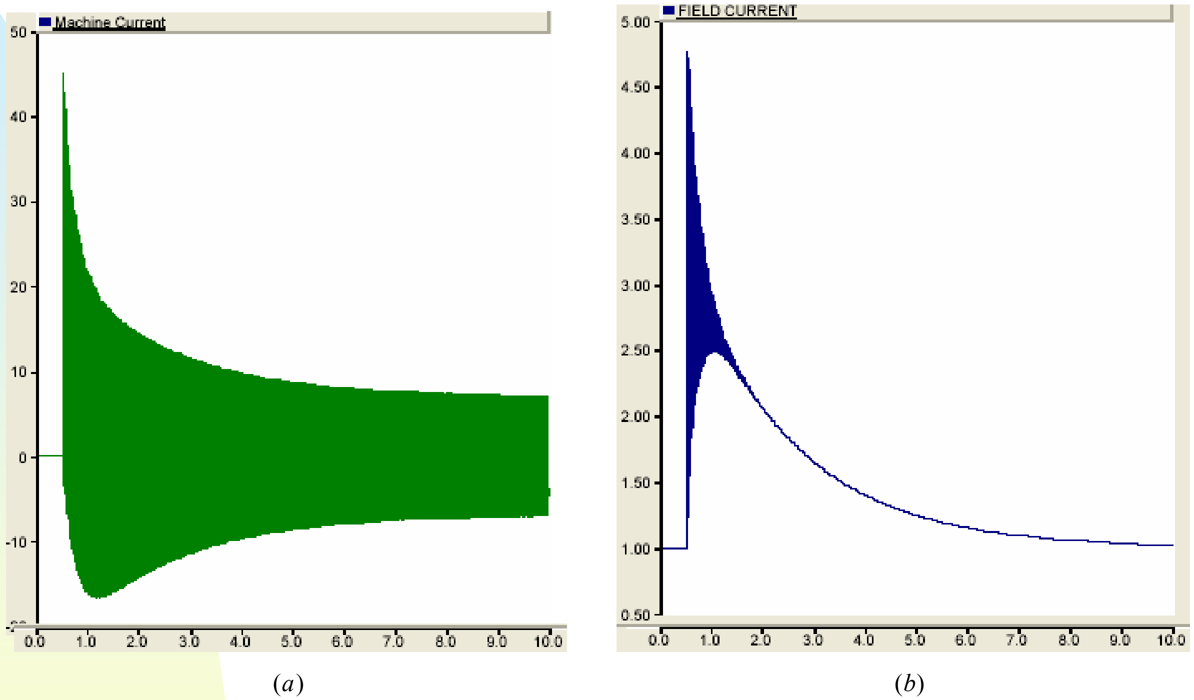


Fig. 9-17 Armature (a) and field current (b), after a sudden short circuit [source: 4].

Representation for Steady State, Transient Stability and Fault Analysis

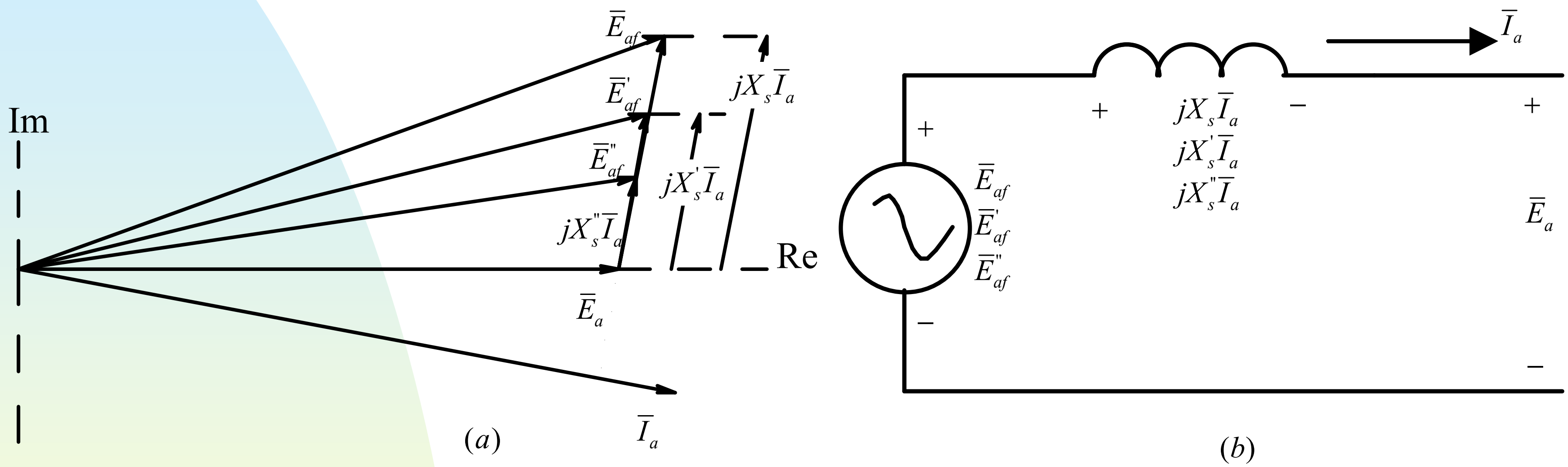


Fig. 9-18 Synchronous generator modeling for transient and sub-transient conditions.

Voltages and Current Phasors with Both-Side Voltages at 1 PU

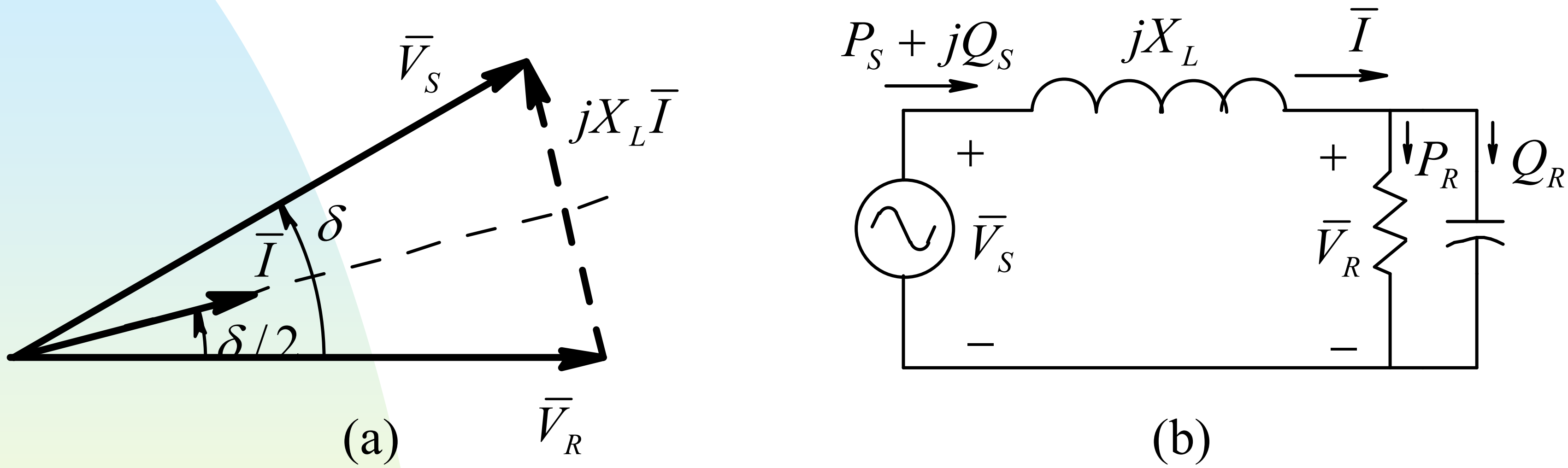


Fig. 10-2 Phasor diagram and the equivalent circuit with $V_S = V_R = 1\,\text{pu}$.

MASTER OF ENGINEERING – Power Systems Option

PROGRAM OF STUDY

Fall Semester			Cr. Hours
ENGR	5100	Methods for Applied Mathematics for Engr	3
EECE	5300	Computer Application to Power Systems	3
CISE	5220	Computer Aided System Design	3
Spring Semester			Cr. Hours
EECE	5310	Power Systems Relaying	3
ENGR	5150	Numerical Methods for Engineers	3
		Elective	3
Fall Semester			Cr. Hours
EECE	5320	Transient Analysis in Power Systems	3
ENGR	5500	Special Problems	3
EECE	5600	Special Topics in Power Systems	3
Spring Semester			Cr. Hours
EECE	5330	Power System Stability	3
ENGR	5500+	Special Problems Continued	3

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CURRICULUM FOR B.S. IN E.E. DEGREE PROGRAM

Freshman Year			**Fall**	**Spr**
ENGL	1010, 1020	Freshman English I & II	3	3
HIST	2010	American History I		3
MATH	1910, 1920	Calculus with Anal. Geom I, Calculus II	4	4
CHEM	1110, 1111	General Chemistry and Lab	4	
PHYS	2110, 2111	General Physics I and Lab		4
ENGR	1020	Freshman Engineering	1	
ENGR	1151	Engineering Design Graphics	1	
ENGR	1000	Freshman Orientation	1	
COMM	2200	Public Speaking		3
			------	------
			14	17

Sophomore Year				
MATH	2110, 3120	Calculus III, Applied Mathematics	4	3
PHYS	2120, 2121	General Physics II and Lab	4	
ENGR	2000, 2001	Circuits I and Lab		4
ENGR	2110	Statics	3	
ENGR	2250	Transport Phenomena		3
ENGR	2230	Computer Programming for Engineers		3
HIST	2020, ENGR 2120	American History II, Dynamics	3	3
ENGL	2110 or 2310	American or World Literature I		3
			-----	-----
			17	16

All students are required to take and pass the Engineering Entrance Examination (EEE) prior to enrolling in upper level (3000-4000) major and engineering courses.

Junior Year				
EECE	2120, 3200	Circuits II, Linear Systems	3	3
EECE	3100, 3101	Design of Digital Logic Systems & Lab	4	
ENGR	3200, 3400	Introduction to Design, Numerical Analysis	3	3
ENGR	3300, EECE 3210	Materials Science, Electromagnetic Theory	2	3
EECE	3061	Advanced Programming Lab	1	
EECE	3300, 3301	Electronics and Lab		4
		Math and Science Elective	3	
		Humanities Elective		3
			-----	-----
			16	16

Senior Year				
ENGR	4500, 4510	Capstone Design Project I, II	1	1
EECE	3410, 3420	Energy Conversion, Power Systems	3	3
EECE	4000, 4001	Control Systems I and Lab	4	
EECE	3500,	Communication Systems, Technical Elective (1)	3	3
ENGR	4201, 4900	Engineer-in-Training Lab (3), Prof. Engr. Seminar	0	1
EECE	4101	Electrical Systems Design Lab,	1	
		Humanities Elective (2)	3	

Technical Electives (1)

3

Social Science Electives (2)

3