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HIGHER TRANSMISSION VOLTAGES-DEVELOPMENTS AND TRENDS

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(Synopsis)

In this conference current trends in the U.S.A. to transmission voltages of 230 Kv and higher to meet future power demands are reviewed.

Factors influencing transmission and station design are considered. These include selection of transmission voltage, choice of conductor, the proportioning and co-ordination of station and line insulation, the further development and application of equipment (transformers, circuit breakers, lightning arresters, etc.,) and other fundamental factors incident to the economy of transmission such as single-and double-circuit tower design and series and shunt compensation.

These as well as other elements of system design and system economics at voltages of 230 Kv and above are analyzed individually and in relation to the overall problem. In addition, the benefits of further rationalization and continued research are pointed out.

The foregoing is amply illustrated with slides. A sound film relating to 380 Kv transmission-line developments in course abroad also is available.

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"HIGHER TRANSMISSION VOLTAGES - DEVELOPMENTS AND TRENDS"

By P. L. Bellaschi, Consulting Engineer

In reviewing the past one cannot but marvel at the achievements that have been attained in the field of power transmission, through seven decades of progress, one milestone after another in rapid succession, and yet it seems now that one of the greatest chapters is in the making at this very time.

Growth of 230 Kv and Higher Transmission Voltages

Slide #1 At present over 350 billion kw-hours are generated annually in the United States. The total installed capacity--about 30% hydro and 70% fuel--amounts to 70 million kw. On the Pacific Coast and in the Northwest where large blocks of power are long distances are present, 230-kv transmission and in one instance 288-kv, have found early and extensive application. With the exception of small but important areas in the East served at 230 kv, power is transmitted in the remaining larger areas of the country at 161 kv, 138 kv, 115 kv and even 69 kv, because of economic reasons.

Twenty-five percent of the total power generated is concentrated in the East North Central industrial region--predominantly steam, and 20 percent in the Mid Atlantic region. The Pacific--where power is largely hydro--and South Atlantic states, together, account for another 25 percent. The remaining 30 percent is widely scattered over the rest of the country.

Slide #2 According to the best estimates, power consumption is expected to double, or more than double, in the next decade. To meet future power needs, correspondingly greater transmission power capability is required, as indicated. The bulk of the electric power generated will be transmitted more and more in the years to come at higher voltages, extensive 230-kv networks, in addition to 300 kv, 315 kv and 345 kv transmission units, embracing large sections of the country, from the Atlantic seaboard extending westward clear almost to the Rocky Mts. with possibly only small gaps separating it from the great and equally extensive 230-kv Pacific network.

Why Higher Voltage Transmission System?

For the following interrelated reasons, because of the need of:

(1) securing increased transmission capability commensurate with future growth in generation and loading.

(2) maintaining flexibility in basic transmission through super-imposing on present networks higher power transmission units commensurate with growing generation and load levels.

(3) establishing higher transmission systems above present systems which rapidly are becoming high-voltage distribution networks.

(4) the imperative necessity of attaining increased transmission capability most economically.

(5) the growing, almost insuperable, difficulties in some regions in securing additional right-of-way requirements and therefore the compelling necessity of utilizing the remaining right-of-way facilities available to the fullest, through the use of larger power transmission units.

(6) integration and coordination with overall growth, diversity of loads, interconnection with contiguous systems and similar considerations.

(7) maintaining our industrial strength in keeping with exigencies -- national defense.

Slide #3 Typical of these considerations is the proposed high-voltage system of the Public Service Company of Indiana, in which 230 kv is super-imposed on present 138 and 69 kv. In this case power is generated at a large modern steam station located on the Wabash, and transmitted at 230 kv to near load centers and stepped down through autotransformers to subtransmission networks.

Slide #4 Representative systems in which EHV's are super-imposed on present high-voltage networks are indicated in A, B, and C.

Typical of straightaway transmission of large bulk of power from remote hydro sources to load centers is exemplified by the Swedish system (A), in which 380 kv is super-imposed on 230 kv. Though transmission distances are less than 300 miles compared to the 600 for the Swedish system, the Hoover Dam-Los Angeles 288-kv system is of this general character.

In (B) you will recognize the Federal Power Columbia system in which transmission at 287 kv or possibly somewhat higher is planned, super-imposed on present

230 Kv.

Finally (C) represents a widespread integrated netowrk practically all steam generation in which site of generation is selected practically at will in relation to load, exemplified by the American Gas and Electric system. In this case 300/315 kv is superimposed on present 138 kv.

Primary Factors in the Selection of Higher Voltage Level

Slide #5 Transmission power capability increases rapidly with voltage. For instance a double circuit 307 kv line is equivalent to or even better than, three single-circuit 230-kv lines.

Slide #6 As illustrated in the example which refers to a 200 mile line single-circuit design, the primary factors in the selection of higher voltages are: (1) the lower annual transmission costs and (2) the greater power capability per circuit. In the case of 200-mile circuits and greater distances stability considerations will limit actual loading below values indicated. The amount of power that can be concentrated in a circuit bears a relation to the total capacity of the system, type of system and to the network. On the premise that for a 2-1/4 million kw system 200 megawatts is permissible in a 230-kv circuit, the system remaining stable upon loss of one 230-kv circuit, then for a 6 million kw system of similar characteristics, 500 to 600 megawatts per line in correspondingly higher transmission units appear justified--in either case concentration in one line is limited to not more than 10 per cent of the system capacity.

A double-circuit line design when more economical would favor lower transmission voltages. In regions where ice formation is a factor, the low resistance of large area conductors associated with the higher voltages inherently presents a problem in ice melting, in favor of the lower voltages unless special conductors are used--this problem however may be minimized with further study. Voltages much above 300 kv because of the greater clearances, present difficulties in hot-line maintenance--this problem likewise may be overcome with further development. But more serious of all and perhaps a determining factor at the very high voltages is radio influence effects.

Considerations in Choice of Conductor

Slide #7 Radio influence being a principal limiting factor, extensive investigations have been conducted here and abroad to determine conductor diameters and types of conductors most suitable for the higher voltages. Varied and extensive experience has established that a 1.10" diameter ACSR Drake conductor is satisfactory for 230-240 kv operation. With this as a reference criterion supplemented by the extensive findings of research investigations, a 1.38" diameter ACSR Pheasant should be equally satisfactory for 300 kv operation, and 1.55" ACSR and 1.60" expanded for 345 kv. Above 345 kv, single conductors become large and unwieldy, but worse still because of the greater surfaces, are subject inherently to streamer formation and entail other effects, further circumscribing their usefulness at the higher voltages. Investigations conducted abroad indicate the advantage of the bundle type of conductor for voltages above 345 kv. The bundle design has the additional important advantage of a 25% lower line reactance but the disadvantage of mechanical complications, heavier tower construction, other possible complications such as sticking of conductors, etc. Much yet remains, to explore more fully the inherent advantages and possibilities of the bundle-conductor line design.

Slide #8 Corona as such is not a determining factor, for the simple reason that corona losses on an annual basis are a fraction only of the I^2R losses even for the higher transmission voltages. Under adverse atmospheric conditions corona losses can well be in the order of the I^2R losses but these conditions endure for a fraction of the total operating time and rarely affect full length of a line simultaneously.

True as it may be that the fruits of much research and development already are at hand to determine in large measure the basic requirements in regard to size of conductors and types, in the design of transmission lines at higher voltages, nevertheless the factors which affect radio influence and dielectric performance at the higher voltages are complex to the extent that experience alone can establish the very top economic and permissible voltage at which a conductor for a particular system, under the conditions of that system, can be operated successfully.

Slide #9 Recognizing that a conductor--a 1.40 or 1.60 inch diameter, may actually be operated in service at somewhat higher voltage than can be anticipated from research studies alone, it appears well justified and a sound approach in planning a transmission system for operation at the higher voltages, at this stage of development in the art, to provide at the outset transformers at the terminals which are equipped with suitable taps so that all possibilities of higher operating voltages can be capitalized to advantage.

Insulation a Major Factor in the Cost of Line and Terminal Equipment

Slide #10 Insulation is a major factor in the cost of the line and terminal equipment, and therefore every effort must be directed to proportion the insulation to the lowest protective levels attainable. On an ungrounded 230-kv system, full 1050-kv insulation would be required. On an effectively grounded system in which 60-cycle overvoltages are limited not to exceed 120 percent normal line-to-ground and switching overvoltages three times, 80 percent arresters are permissible and correspondingly 80 percent BIL applicable. On a solidly grounded system 60-cycle overvoltages would be held under 110 or 112 percent normal line to ground, and with the application of breakers of good behavior and no restrike, switching voltages limited to less than 2 or 2-1/2 times; in this case 75 percent arresters are applicable and correspondingly a BIL of 825 kv can be specified. And finally on very solidly grounded systems on which overvoltages are limited further, 70 percent BIL or 750 kv for 230 kv should be attainable. Likewise material reduction in the line clearances and insulation are feasible through solidly-grounded operation, rationalization in system and transmission design and application of modern protective equipment.

Slide #11 In addition to the reduction in cost of equipment resulting from a reduction in BIL, other tangible benefits are the improved characteristics and performance, paring down of weights and dimensions, and especially the lower impedance realized. It is well to note that a 1% reduction of transformer impedance corresponds in impedance value at 288 kv to about the equivalent of 9 miles of line. The actual economic value would be less but nevertheless quite tangible.

Slide #12 For maximum economy a large number of BIL's in small steps would be desirable but this arrangement may not be in the best interest of standardization in equipment design. To overcome this difficulty transmission voltage can be selected and proportioned to the desired standard BIL at the required level as indicated.

Factors Influencing Future Transmission

Viewing current developments and trends from an overall vantage point, we find on the one hand the need for higher transmission capabilities and the urge for more economical transmission of large blocks of power, both attainable through the use of higher voltages. On the other hand technological advances and various developments in transmission design make possible higher power capabilities and economies in the amounts required in many cases, without recourse to the very high voltages; such factors for instance are series compensation, further development and application of bundle conductors, the relative economics of double and single-circuit line design, application of rapid clearing and reclosing breakers in combination with the new and markedly improved methods of control and communication, more rational application of reactive system design, not to mention some of the other factors already discussed. While it is true that the AC system has scored a decisive victory over DC during the past five years, it is not apparent either in view of the foregoing that 230 kv has been relegated to secondary importance at all, in the future development of electric power transmission in the U.S.A.

Conversion of Present Lines to Higher Voltages

Slide #13 The conversion of some of the present 161 kv, 138 kv and 115 kv circuits for 230 kv operation is more than an academic question. Various modes of transformation that can be applied are indicated. In one instance, 161 kv ACSR conductors are being removed, sent to the factory for the addition of a layer of aluminum conductors, restrung and suitable transformation at terminals provided to step up to 230 kv. The adaptation of bundle-conductor design to present single conductor 115 kv and 138 kv circuits for 230 kv operation is another possibility.

Importance of 230 kv in Future Power Developments

Slide #14 The role 230 kv will assume in future power development is amply apparent from the transmission system growth anticipated in the current decade. For instance the 9,000 or 10,000 circuit miles of 230 kv now installed are expected to more than double in the coming eight or ten years. In a decade proportionately more and more additional power of necessity will be transmitted at 230 kv.

Slide #15 For every circuit mile of 230 kv line there are two thousand kva of 230 kv transformers installed. Some 20 million kva or more of 230 kv transformers will be added in the next eight or ten years.

Slide #16 Today a total of about 600 three-pole 230 kv breakers are installed. This number should more than double in the next decade.

Slide #17 With this volume of 230 kv equipment ahead important technological developments directed to more economical and functionally more effective 230-kv designs must be expected. This would be the case for power circuit breakers as indicated as well as for all other station and line equipment--lightning arresters, transformers, capacitors, line and station design as well as generating equipment.

Power Transmission at Extra-High Voltages in the U.S.A. and Abroad

Slide #18 Where economic and technological requirements dictate higher transmission voltages, these will naturally find application. The trend in this direction already is quite impressive. In fact, as indicated in the tabulation, a "rush" to the E HV's seems to be underway, one country outdoing the other so-to-speak.

Summary and Conclusions

Among the more important conclusions three stand out conspicuously:

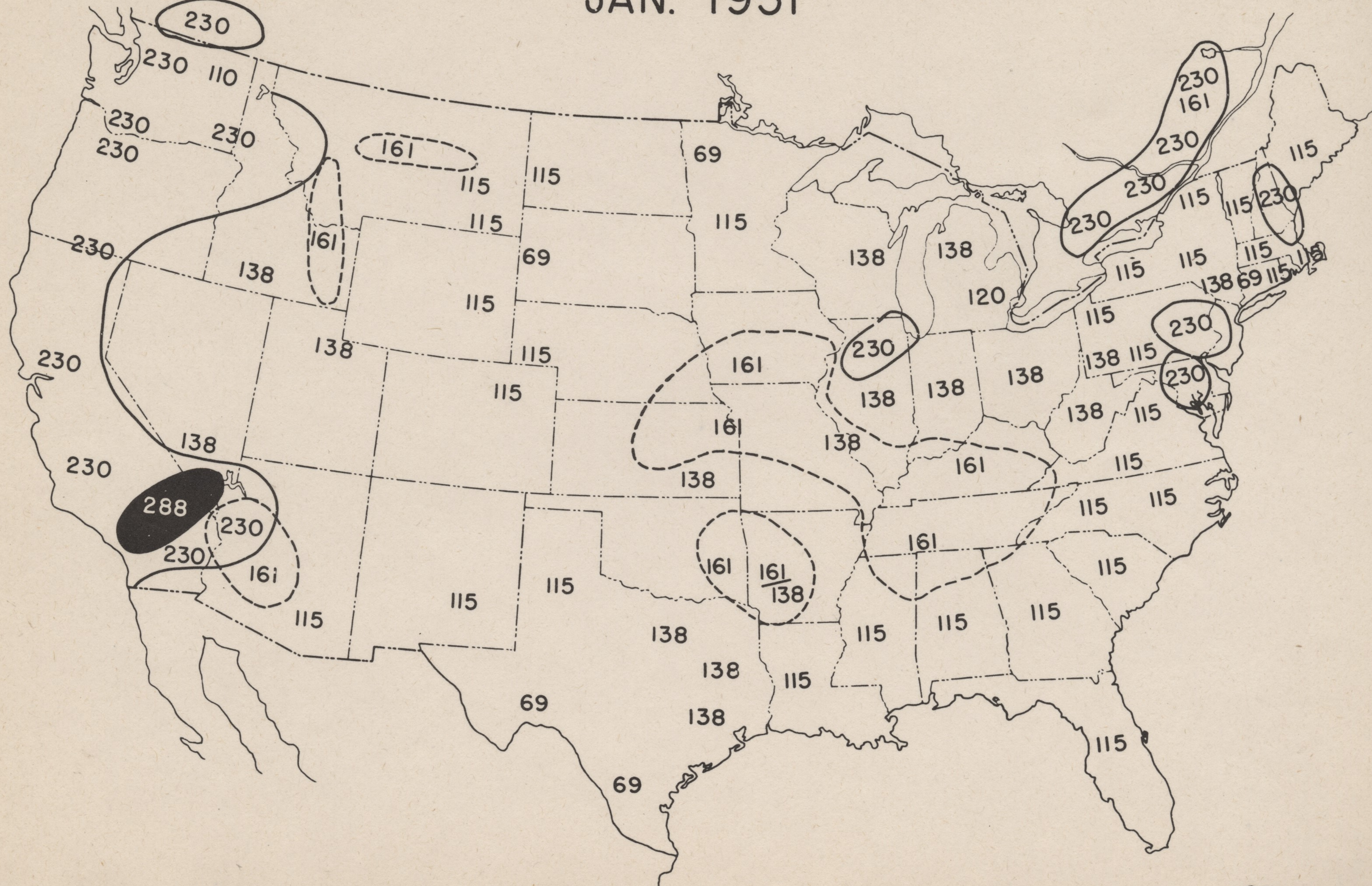
(a) A nation-wide trend to 230-kv transmission superimposed on present 138 kv and 115 kv systems.

(b) The importance of 230 kv in the future economic power development and growth in the U.S.A.

(c) The development of higher transmission voltages above 288 kv in the U.S.A., Canada, Sweden and elsewhere - England, France, Germany, etc.

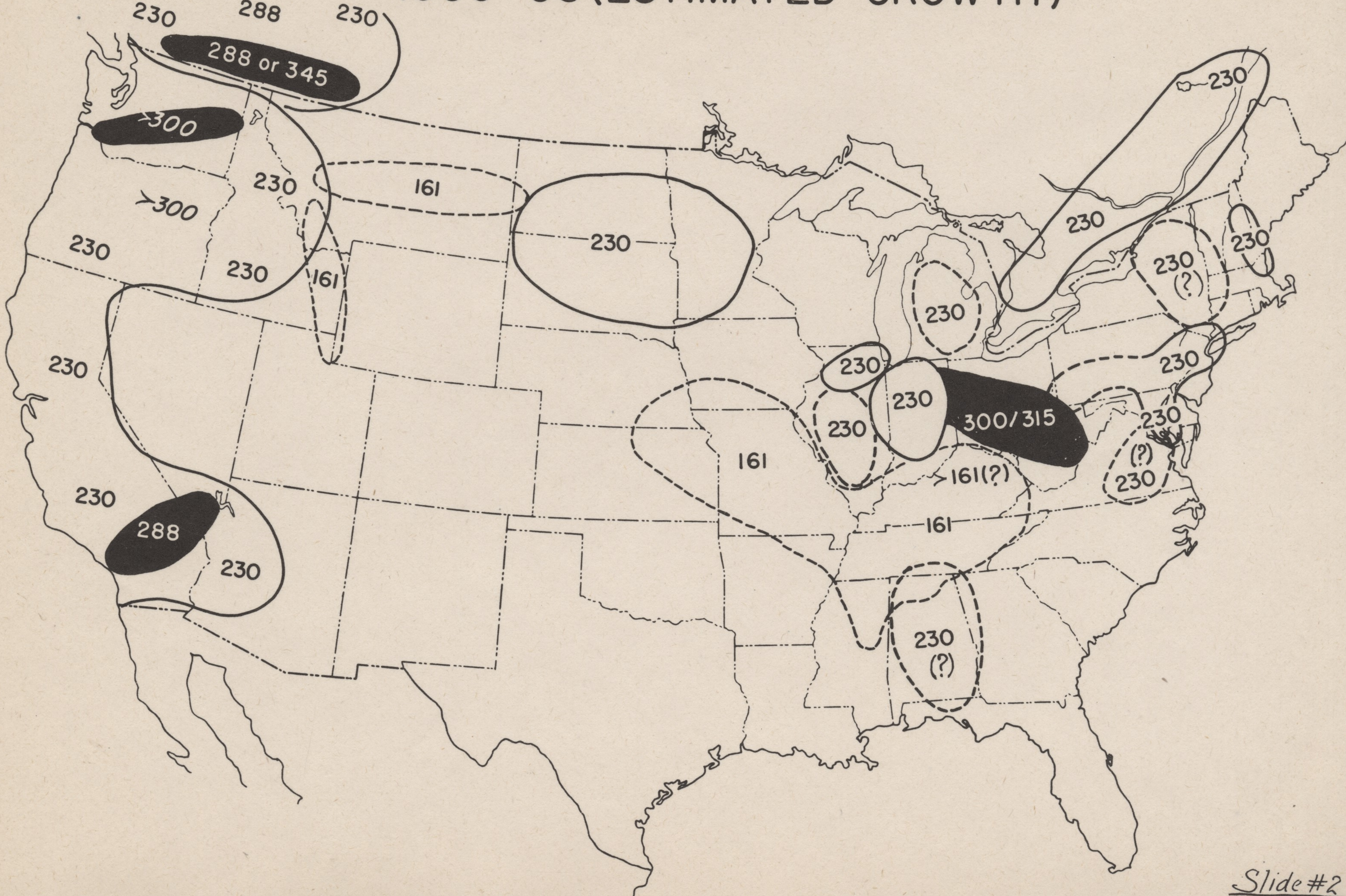
As stated in the beginning an important chapter in the field of power transmission is in the writing during this decade. Let us see that it shall stand as a solid pillar to the future growth and well-being of the country for years to come and that it shall be worthy of the fine traditions established by our predecessors in this field.

TRANSMISSION VOLTAGES
JAN. 1951



Slide #1

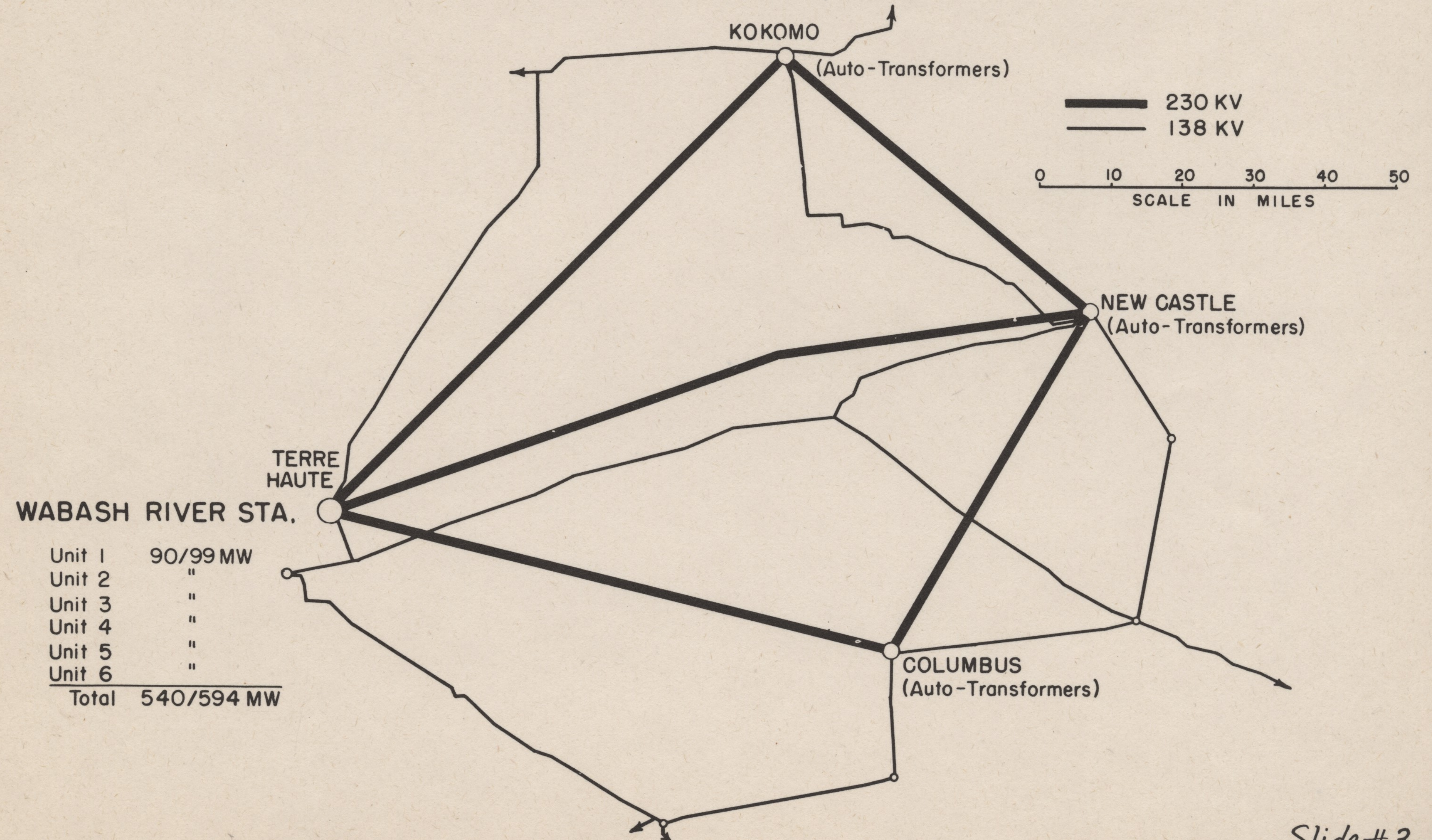
TRANSMISSION VOLTAGES 230 KV AND ABOVE 1956-58 (ESTIMATED GROWTH)



Slide #2

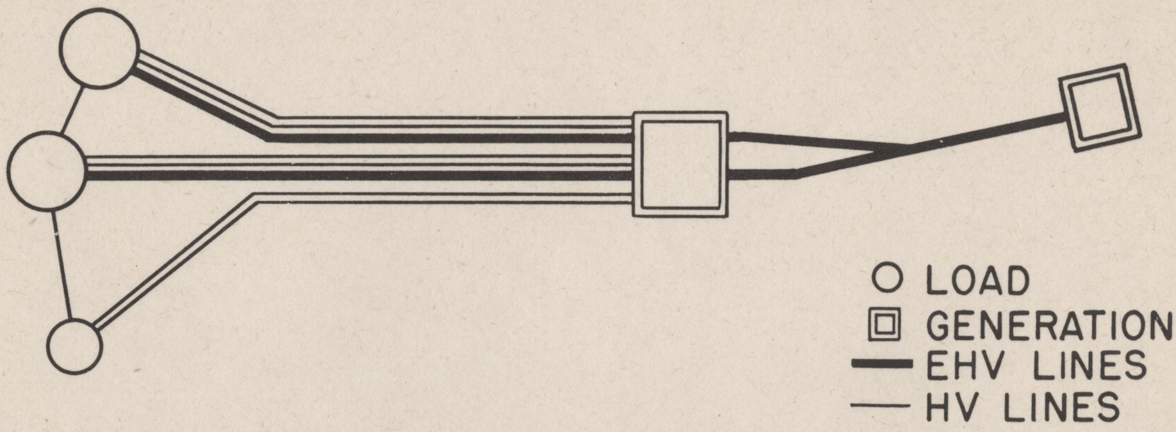
TYPICAL CASE OF 230 KV SUPERIMPOSED ON PRESENT 138 KV AND 69 KV

(P.S. CO. OF INDIANA, INC.)

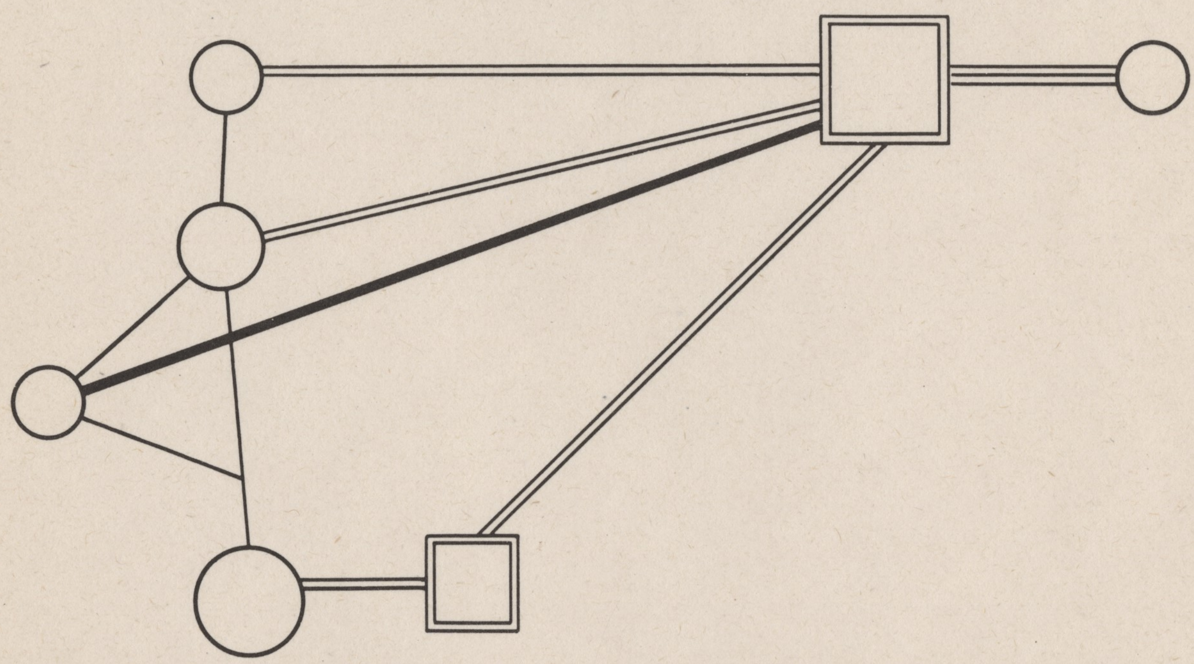


Slide #3

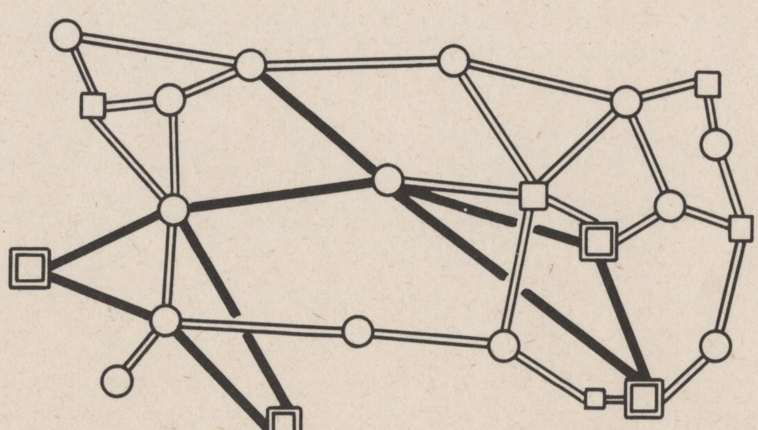
TYPES OF SYSTEMS



(A) VERY LONG DISTANCE BULK TRANSMISSION



(B) LONG DISTANCE BULK TRANSMISSION



(C) WIDESPREAD NETWORK (INTEGRATED)

Slide#4

RELATIVE POWER CAPABILITY
V.S.
TRANSMISSION VOLTAGE
(200 MILE LINE)

TRANSMISSION VOLTAGE-KV	RELATIVE POWER CAPABILITY OF LINE
230	1.00
288	1.42
307	1.59
345	1.90
380 (SINGLE)	2.20
380 (BUNDLE)	2.75

Slide #5

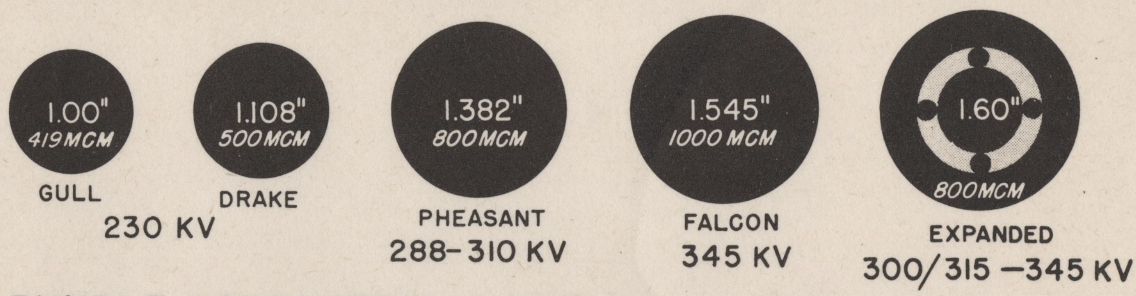
RELATIVE ANNUAL TRANSMISSION COSTS
200-MILE SINGLE CIRCUIT

TRANSMISSION VOLTAGE-KV	CONDUCTOR ACSR-MCM	ECONOMIC LOADING-MW	RELATIVE COST
230	500	185	1.00
288	800	280	0.82
307	950	325	0.76
345	1240	400	0.70

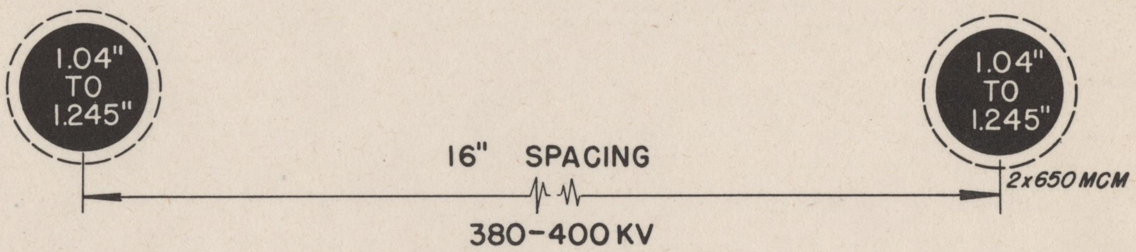
Slide #6

SIZE OF CONDUCTOR
VS.
TRANSMISSION VOLTAGE

SINGLE CONDUCTOR ACSR (FULL SCALE)



BUNDLE CONDUCTOR ACSR (FULL SCALE)



Slide #7

I - COMPARABLE RADIO INFLUENCE

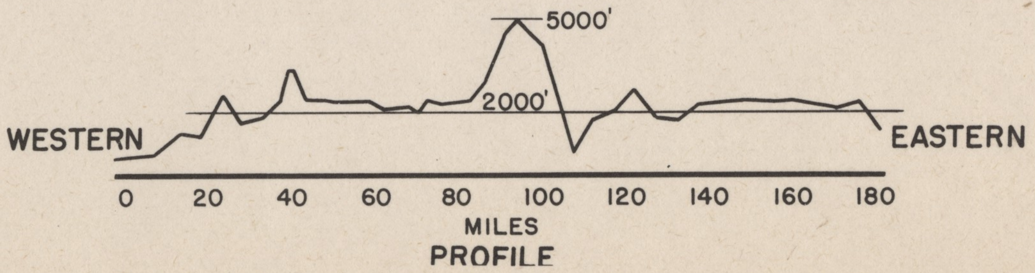
CONDUCTOR (DIA.)	1.10"	1.38"	1.8"- 2.0"
OPERATING VOLTAGE (KV)	230	300	380

II - ANNUAL CORONA-LOSS (KW/MI)

FOUL WEATHER	12	30
FAIR WEATHER	1.25	3
AVG. (ANNUAL)	2.5	6

III - AMBIENT AND CLIMATIC CONDITIONS: PRECIPITATION; ALTITUDE; GEOGRAPHICAL CONDITIONS; OTHER FACTORS

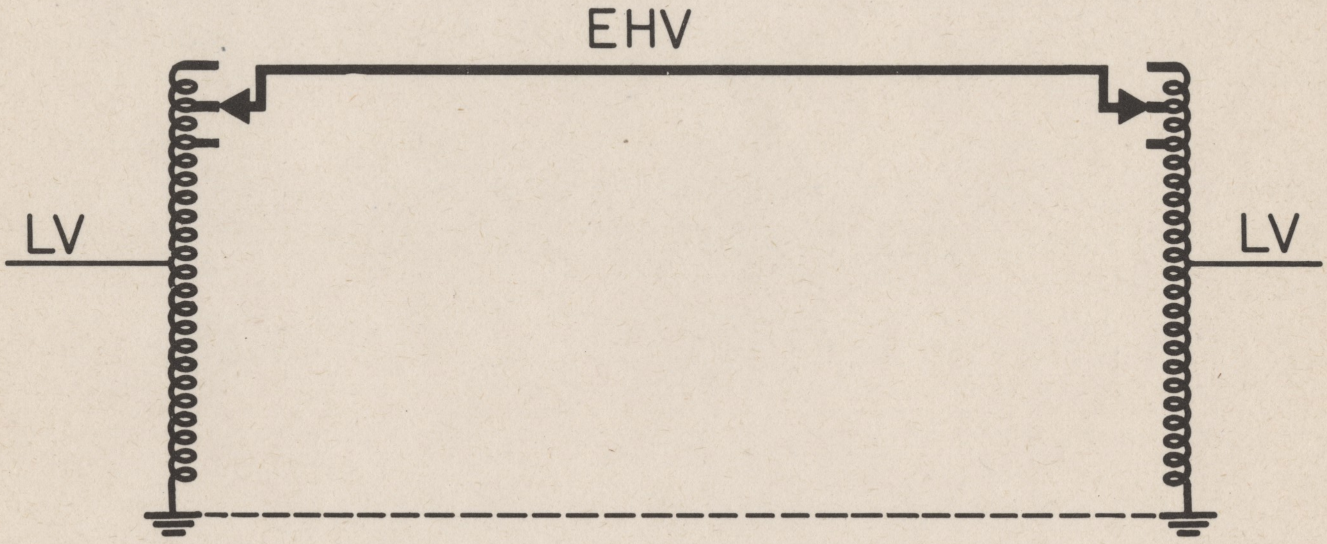
(TRANSMISSION LINE)



Slide #8

MAXIMUM VOLTAGE SUITABLE FOR CONDUCTOR DETERMINED FROM EXPERIENCE

APPLICATION OF TAPS TO TRANSFORMERS



Slide#9

STATION INSULATION PROPORTIONED TO PROTECTIVE LEVEL ATTAINABLE

SYSTEM VOLTAGE (KV-RMS)	ISOLATED SYSTEM 100% ARR. (BIL-KV)	EFFECTIVELY GROUNDED 80% ARR. (BIL-KV)	SOLIDLY GROUNDED 75% ARR. (BIL-KV)	VERY SOLIDLY GROUNDED 70% ARR. (BIL-KV)
230	1050	900	825	750
288	1300	1050	(975)	900
345	1550	1300	(1175)	1050

Slide#10

REDUCTION IN COST OF TRANSFORMERS
AND
IMPROVED PERFORMANCE REALIZED BY REDUCTION IN BIL

	1050 BIL	750 BIL
COST __________	100	70
IMPEDANCE	100	75-80
WEIGHTS, DIMENSIONS, SHIPPING WEIGHTS ____________		REDUCED
NO LOAD LOSSES, COPPER LOSSES ______________		REDUCED

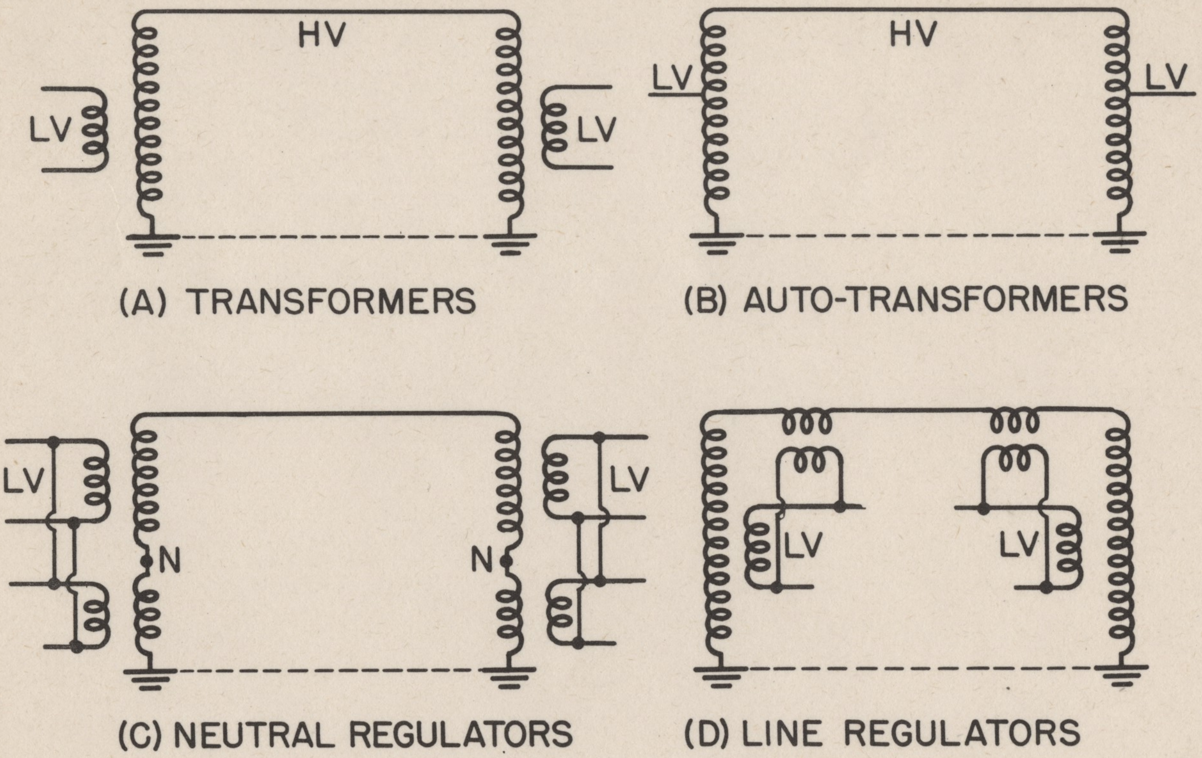
Slide #11

TRANSMISSION VOLTAGE PROPORTIONED TO BIL

BASIC INSULATION LEVEL (75%)	TRANSMISSION VOLTAGE
(KV)	(KV/RMS)
(975)	288/302
1050	308/322
(1175)	345/362
1300	380/400

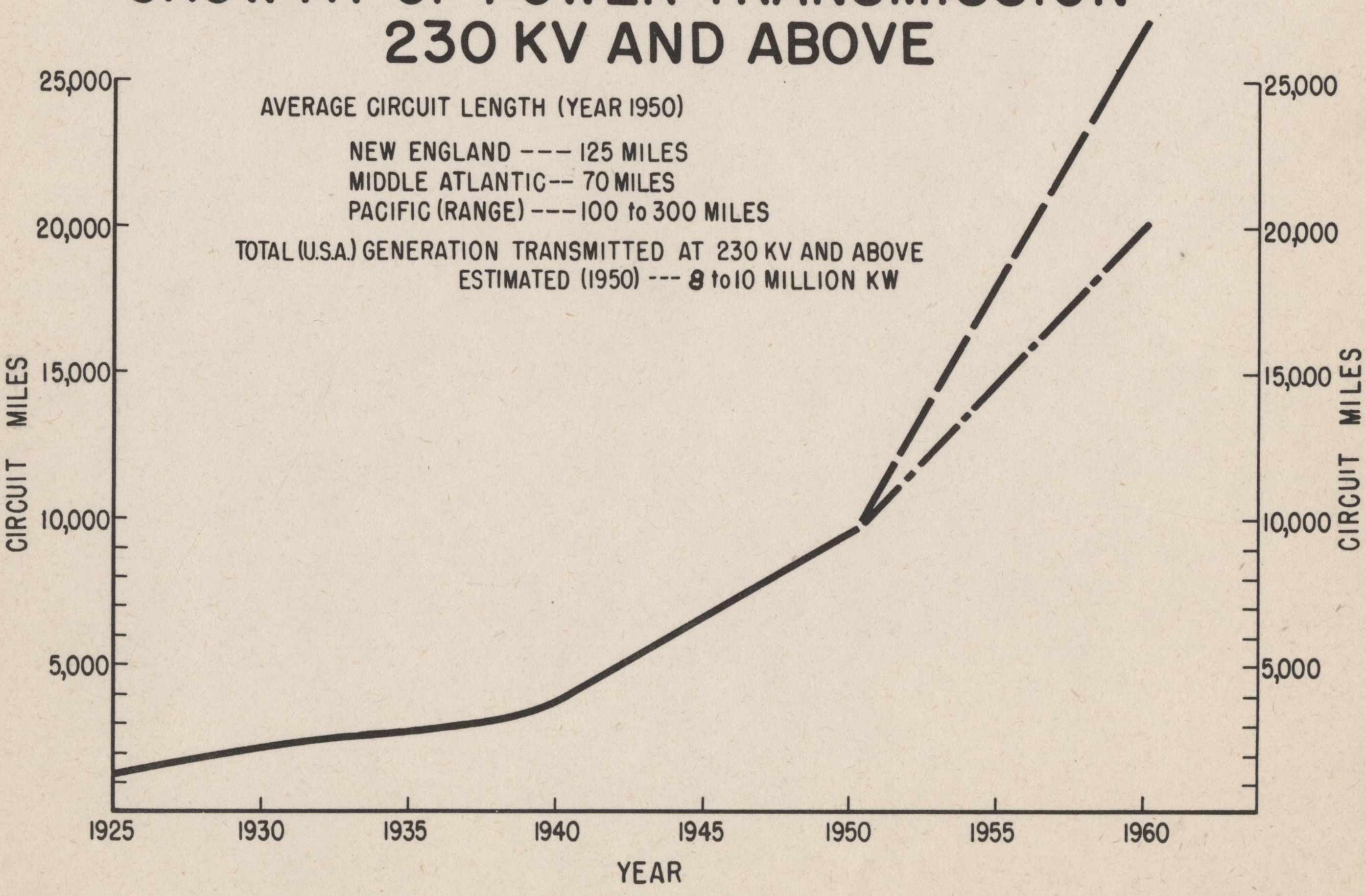
Slide #12

MODES OF TRANSFORMATION



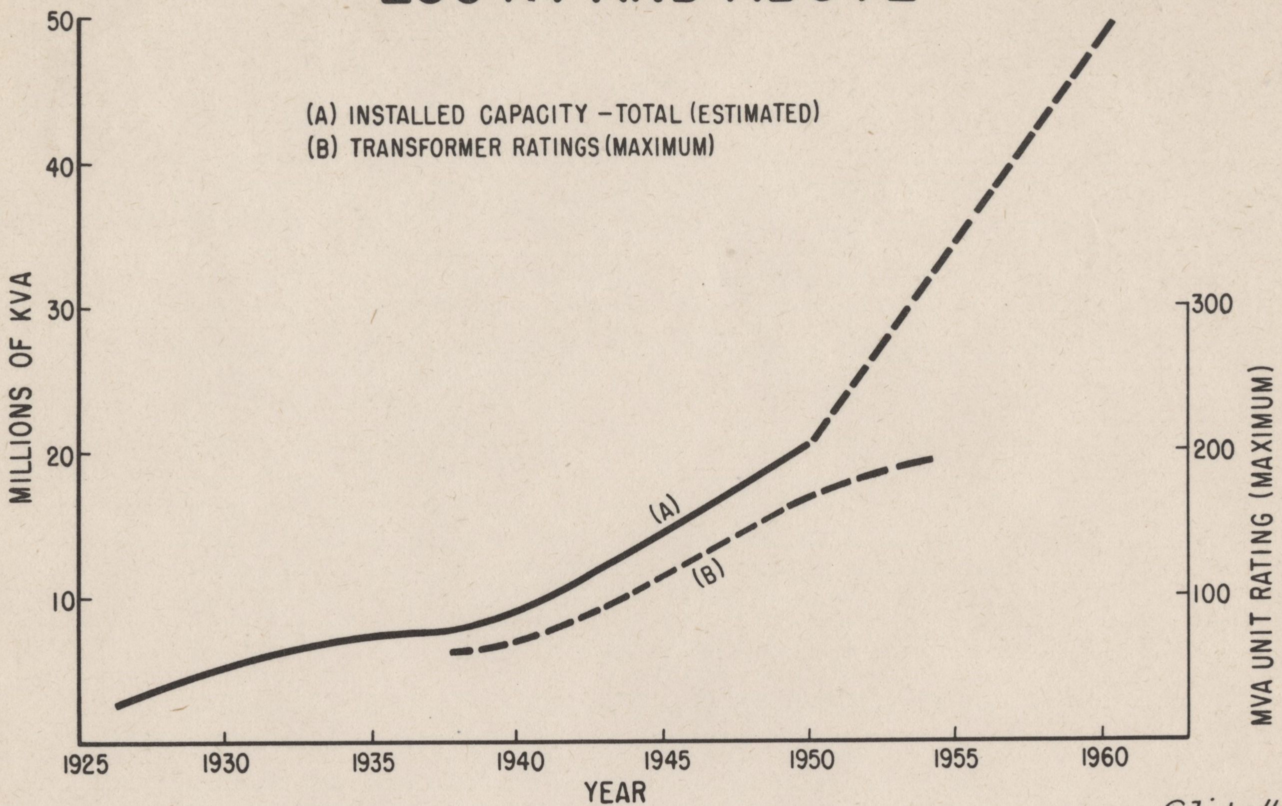
Slide #13

GROWTH OF POWER TRANSMISSION 230 KV AND ABOVE



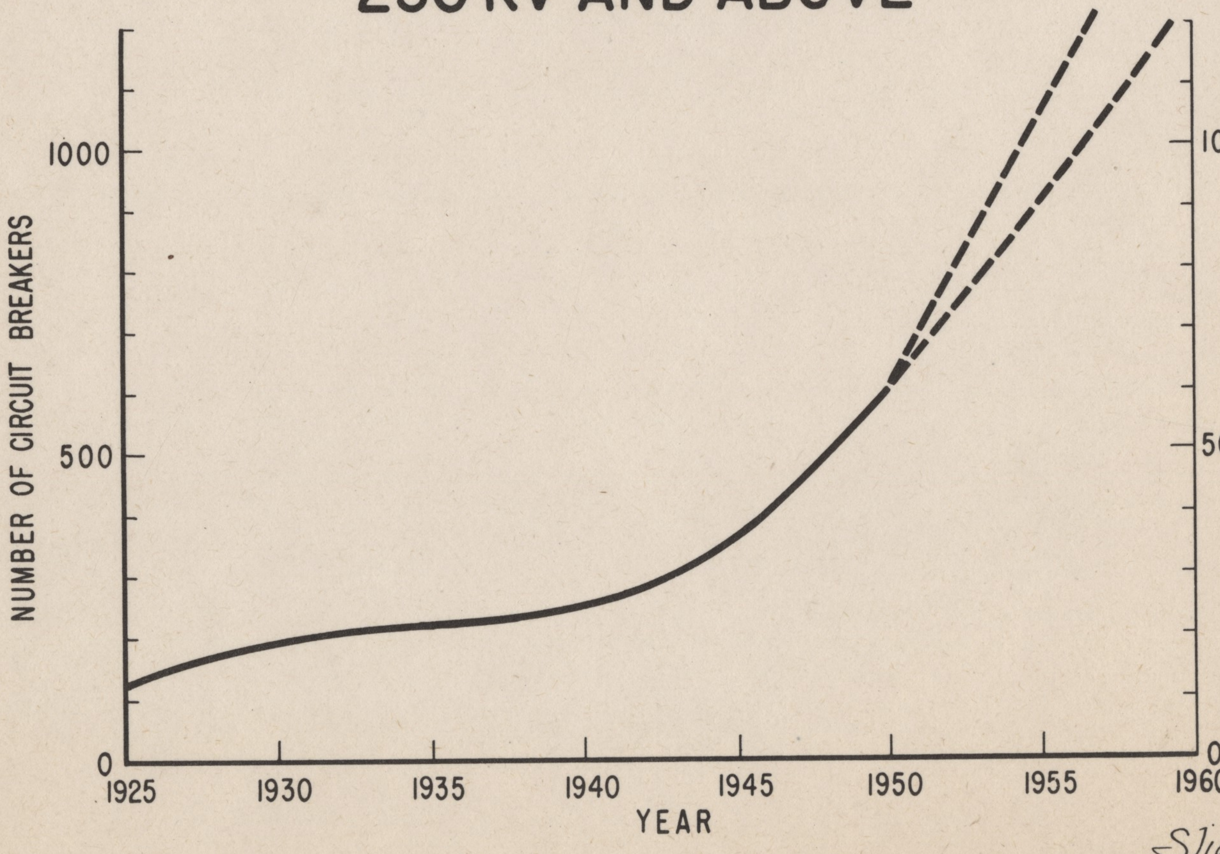
Slide #14

GROWTH OF POWER TRANSFORMERS 230 KV AND ABOVE



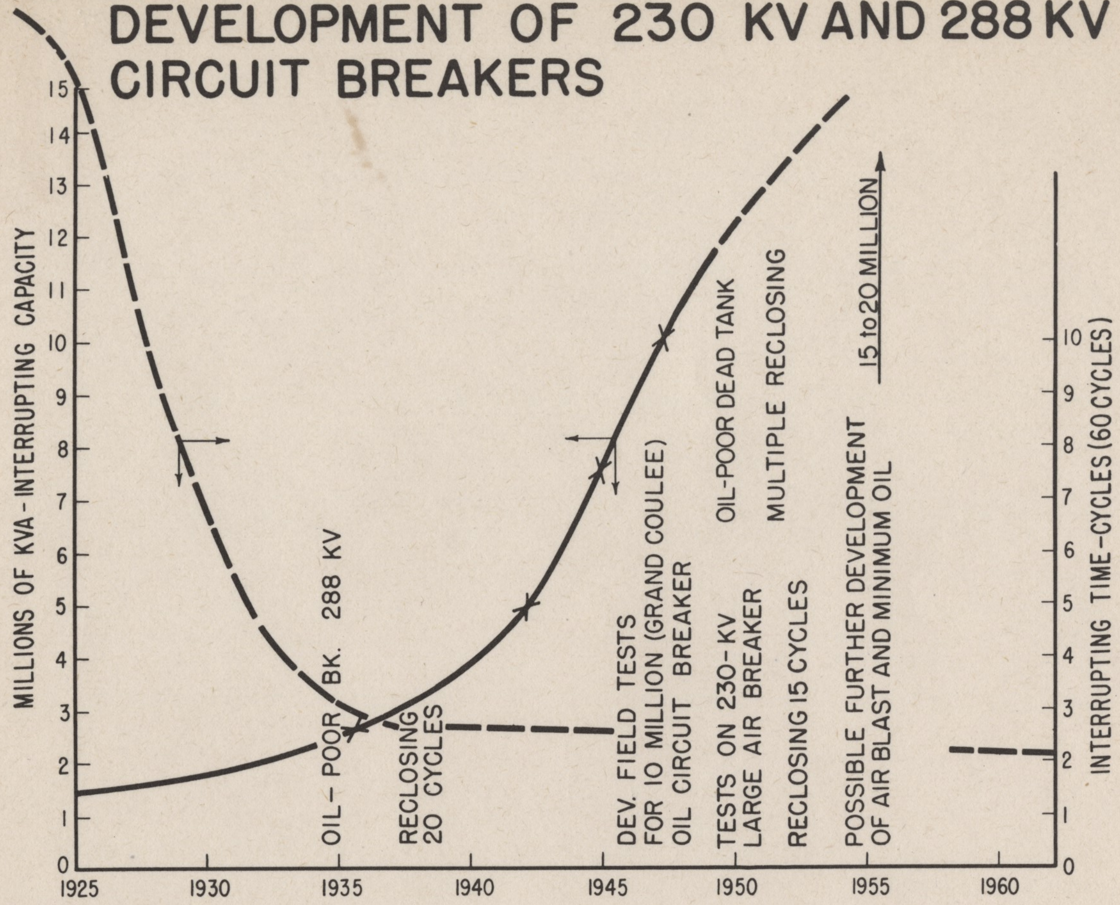
Slide #15

GROWTH OF POWER CIRCUIT BREAKERS 230 KV AND ABOVE



Slide #16

DEVELOPMENT OF 230 KV AND 288 KV CIRCUIT BREAKERS



Slide #17

PROPOSED POWER TRANSMISSION AT EXTRA-HIGH VOLTAGE

COUNTRY	VOLTAGE	CONDUCTOR
U.S.A.		
S.W. PACIFIC	288	HH-COPPER 1.40"(IN SERVICE)
N.W. PACIFIC	295/310	ACSR 1.382"
EAST N. CENTRAL	300/315---345	ACSR 1.60"(EXPANDED)
CANADA		
BRITISH COLUMBIA	288 or 345	—
SWEDEN	380/400	BUNDLE ACSR
FRANCE	380/400	BUNDLE ACSR
ENGLAND	275	BUNDLE ACSR
GERMANY	300	HH-COPPER 1.65"
ITALY	>230 (FUTURE)	—
SWITZERLAND	>230 (FUTURE)	—
RUSSIA	400(?)	BUNDLE (?)
SOUTH AMERICA	230	ACSR
MEXICO	230	ACSR

Slide #18