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Economical Direct Feeding of Far- Distance Zones from High-Voltage Transmission Lines.

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ECONOMICAL DIRECT FEEDING OF FAR- DISTANCE ZONES FROM HIGH-VOLTAGE TRANSMISSION LINES

تغذية اقتصادية مباشرة للمناطق النائية من خطوط الجهد العالى

BY

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ملخص :

يقدم هذا البحث نموذجا رياضيا لشبكة سعوية أو حثية تستخدم القدرة المفقودة من خطوط الجهد العالى وذلك لتغذية مساحة عامرة بالسكان خالية من منابع الكهرباء وبعيدة عن نظم التوزيع مما يتعذر معه تغذيتها منه بسبب الحالة الاقتصادية.

ولذلك يقدم هذا البحث مغذيا جديدا مقترحا يعتمد أساسا على مرور خطوط الجهد العالى بالمنطقة المراد تغذيتها وبعض العناصر الإستاتيكية ويقدم أيضا مقارنة بينه وبين المنبع التقليدى من الوجهه الاقتصادية لجهود مختلفةولأبعاد مختلفة عن أقرب مكان للتوزيع. والبحث قام أيضا بحساب الحالات العابرة فى حالة وجود أخطاء خفيفة اوكبيرة ومدى تأثير المفاتيح على النظام. وتوصل البحث الى أن المغذى المقترح يعتبر هو المثالى حسب الشروط المحددة فىالدراسة.

ABSTRACT :

This paper presents a mathematical model of economical sources for capacitive take-off power network. Also , the paper illustrates the comparison between transformers data and power take-off capacitance from HVTL (220kV). This indicates that the same results of economical regions utilizations and take-off network are nearly identical. Economical radius of distribution system is chosen as a function of surface density load (kW/km^2). The dimension of electrical power region circle is determined by the value of economical radius of ditribution network. The component of capital charge produces an effect on selected installation at reactive power regime of transmission line. The component of reactive power installation compensated cost is determined by the cost of compensated device. The economical criteria at choice of optimal variant may be specified by the complete expenses. The power take-off is considered as the best economical efficient source in the case when the distance from the distribution system is larger than 20 km..

INTRODUCTION

Electrical high voltage transmission lines (EHVTL) pass over small areas , in which people live without any electrical energy sources. Those consumers work in agricultural and light industrial operations. The electric power supply from distribution system is very expensive and not economical .

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The power take-off from high voltage transmission lines (HVTL) by using stepdown transformers, capacitors and reactors may be used to feed countries , as economical source.

Special singularity of capacitive take-off power network may be considered as resonance circuit consisting of capacitive divider and non-linear inductive of transformation device. Therefore , the voltage of capacitive transformer at transient processes may induce appereciable distortion of secondary voltage. This depends on the network pmeters, moment of switching, disturbance type, character and value of secondary load current. At unsuitable relationships of parameters, ferroresonance appears in capacitive transformer voltage network [1&2] .

For practical purposes, it must be known how autoparametrical oscillating condition initiates, like dynamic transient process. For evaluation of capacitive take-off power networks, special computer programs are used. The computer programs permit to regenerate non-linear characteristics and modify parameters in wide ranges, which represent serious problems in the case of any physical model [3] .

STUDY OF PROPOSED FEEDING:

As shown in Fig. 1, the experimental investigations of capacitive voltage divider simulator by extent of exposure can be considered as two typical disturbance types :

i) Light or small disturbance-occurs when capacitive voltage divider (CVD) networks are connected;

ii) Heavy or large disturbance - occurs when short circuit, at intermediate transformer terminals, is switched off.

Transient process analysis, at small disturbances, is very important for determining values and durations of secondary voltage distortion.Also, it is suitable, at large disturbance , for pereventing ferroresonance stable conditions [4].

At large disturbance, the reactor volt-ampere characteristic may affect the transient process initial conditions. This is true because short circuit current value depends on the non-linear inductive compensating degree [5] .

For studying transient processes, selection of transformer equivalent circuit is very important because resonance property is mainly determined by the relationship of volt-amperes characteristics of intermediate transformer divider at no-load.

The known non-linear models of local single-phase, two-windings transformer are based on the distribution or division of the magnetic flux,generally, for two transformer coils. These coils are closed by the steel core. Leakage flux is coupled with separated coils, which are closed out side of core. Constructed T-nominal equivalent circuit by these models is very suitable to represent normal load operations and transient processes conditions. But these models are

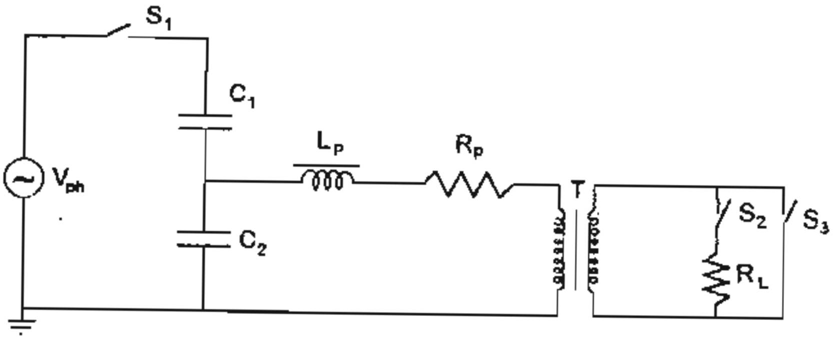
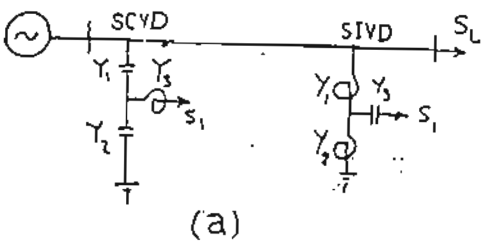


Fig. (1) :Capacitive take-off power network model.



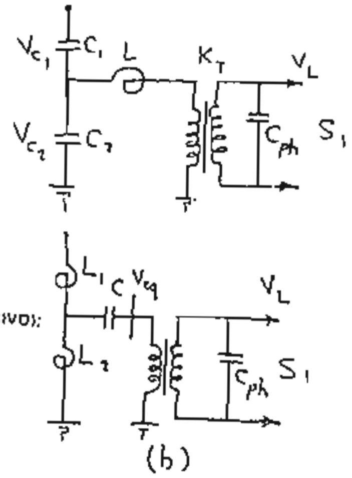


Fig.2 variety homogeneous of compensating voltage divider (CVD) :
a- Capacitive and inductive compensating voltage divider (SCVI & SIVD);
b- Substation circuits .

unsuitable for researching conditions of transient processes in the case of separated coils with unsymmetrical loading, for example magnetization current surge [6].

For satisfying this and other requirements, it is necessary to use the π - nominal equivalent circuit of transformer. The transient process in networks with capacitive take-off power research, can be classified into three modes (Fig.1.). These modes are :

i) Connecting capacitive take-off power device, in this mode key S_1 is closed and keys S_2 & S_3 are opened;

ii) Connecting load, in this mode keys S_1 and S_2 are closed and key S_3 is opened, and .

iii) Short circuit of load in this mode all keys S_1, S_2& S_3 are closed.

CALCULATION OF CAPACITIVE TAKE-OFF POWER (CTP) NETWORK.

An urgent problem during calculations is the security of small voltages at selected condenser in the case of maximum load. It allows to apply a self condenser, like auxiliary apparatus, which have low isolation for obtaining low cost network. Decreasing voltage V_{c2} may be controlled by increasing selected capacitance. Much accuracy may determine optimal parameters by comparing different variables. But choosing of orientation ability condenser capacitive at known value of capacitance determine the relationship of it's cost with equivalent voltage value. The cost of condenser may be written approximately as :-

$$A = K_1.C.V^2 \qquad (1)$$

Where : K_1-coefficient, which characterizes construction data type ;
C and V- capacitance and voltage of condenser.

From equation (1) and according to condenser cost A_{c2}

$$V_{c2} = [A_{c2}/(k_1C_2)]^{1/2} = \{ (A_{c2}V_{eq}) / [k_1(V_{ph} - V_{eq}) C_1\}^{1/2} ; \qquad (2)$$

$$C_2 = C_{eq} - C_1 = C_1 [(V_{ph} / V_{eq}) - 1] \qquad (3)$$

Voltage on lower divider element (Fig.2.a) is determined by voltage on transformer and reactor with constant part of $V'_L = V_T = V_{eq}$ and variable part of V_L, which are changed in amplitude and phase :-

$$V_{c2} = V_{eq} + V_L = V_{eq} + j I X_{Leq} \qquad (4)$$

Absolute voltage value is :-

$$V_{c2} = \{V_{ph}^2 (C_1 / C_{eq})^2 + (2S \sin \Phi /w C_{eq}) + S^2 / (V_{ph} w^2 C_1^2)\}^{1/2}$$
$$= \{V_{eq}^2 + (2 P \tan \Phi / wC_{eq}) + P^2 / (V_{eq}^2 w^2 C_1^2 \cos^2 \Phi)\}^{1/2} \qquad (5)$$

Comparing between Eq (5) and Eq (2) we obtain the relation $A_{c2} = f(V_{eq})$. For simplification of analysis without errors , which have the following relation :-

$$C_1 << C_2 = C_{eq}$$

Then:

$$A_{c2} = V_{eq} V_{ph} K_1 C_1 + (S^2K_1 / V_{eq} V_{ph} w^2 C_1) + (2S K_1 \sin \Phi) /w \qquad (6)$$

Equivalent voltage value, which according to minimum cost of selected condenser is obtained by equating the derivative of expression (6) by V_{eq} to zero, from this:-

$$V_{eqmin} = S /wC_1V_{ph} = V_{Lmax} \qquad (7)$$

$$V_L = P/\left(wC_{eq}\ V_{eq}\ \cos\phi\right) = P/\left(wC_1\ V_{ph}\ \cos\phi\right) \qquad (8)$$

It is more suitable to specify the equivalent voltage to voltage on reactor at full load.

Using the unequally values of $V_{eq} = V_L$,the condenser capacitance value becomes:-

$$C_2 = C_1 [(V_{ph} / V_{eq}) - 1\} \qquad (9)$$

From this discussion we notice that, at large take-off powers, which give rise to high value of V_L and V_{C2},a dreasing value V_{eq} for reducing transformer insulation and auxiliary equipments is required. In these cases, when allowable voltage value of selected condenser is given condition at computing take-off network, may be used for determining its capacitance by differentiating formula (5) :-

$$C_{eq} = [(WC_1^2 \; V_{ph}^2) \; / \; (W^2C_1^2K_2^2V_{ph}^4 - S^2)]. \; \{S \sin \phi + [W^2C_1^2K_1^2V_{ph}^2 - S^2\cos^2 \phi \;]^{1/2}\} \qquad (10)$$

where :- $K_2 = V_{c2} / V_{ph}$

At choosing of upper elements divider, its capacitance is found at selected power and allowable voltage drop on reactor values . From Eq. (8) :-

$$C_1 = P / (WV_{ph} V_L \cos \phi \;) \qquad (11)$$

For take-off power networks, when linear relationship of condenser is used, the relationship $V_{c1max} \leq V_{ph}$ is rigorously specified condition. Check of its observance may be fulfilled by the following formula :-

$$S = WC_1V_{ph}^2 \{(C_2 / C_{eq}) \sin \phi \; + [1-(C_2^2/ C_{eq}^2]^{1/2}\} \qquad (12)$$

With the calculation of preceding we can specify the following sequence of the main parameters of capacitive take-off power :-

1- V_{Lmax} is determined by given values of S_1, C_1 and V_{ph} ;
2- V_{eq} may be chosen according to V_{Lmax} ($V_{eq} \approx V_{Lmax}$);
3- Capacitance values are $C_{eq} = C_1(V_{ph} / V_{eq})$; $C_2 = (C_{eq} - C_1)$;
4- Manufacturing evaluation of V_{c2max} ; V_{Lmax} and V_{eq};
5- Check allowable given load by voltage value of condenser C_1;
6- By take-off power S and equivalent voltage may determine step-down transformer parameters and choose transformer type;
7- Small regions of loads with transformer current I_t calculation, selected device characteristics V_{c2} , V_{c1} and V_L are determined by analysis or graphical method;
8- On the base of the obtained characteristics , main and auxiliary devices insulation degree and their security is checked when using capacitive equipment;
9- Make calculation of take-off power device external characteristics and check at approximately variable equipments active resistance values.

ECONOMICAL CALCULATIONS

Using economical criteria to select optimal variant of EPS in order to reduce expenses and obtain sufficient accuracy, complete investments may be specified. The researches have shown that, for defined initial economical data, the complete investments counting the power loss, global embedding level fuel, fuel transport and reduction of expenditures are changed.

Fig.3 shows the comparison between the data of transformers and power take-off capacitance from HVTL (220kV) . From this figure, their indicators give the same results-economical regions utilizations of take-off network are nearly identical.

The complete investments of power take-off network, in general may be formed as :

$$K_P = \pi R_e^2 (1/\cos\phi_a) K_d P_o \{(2C_d + C_c)\sqrt{(V_n + \Delta V - \Delta V_l)/V_e - 1} + C_s + C_{rv}\}$$
$$+ L_l C_l + \Delta P_\Sigma a + \Delta E_\Sigma b_T K_T - \nu K' \pm K_Q \tag{13}$$

Where :

R_e	economical radius of distribution system,km;
P_o	surface density Load, Kw/Km^2 ;
$\cos\phi_a$	weighted average power factor;
K_d	demand factor;
C_d, C_c, C_s	the cost of voltage divider, compensation device and step-down transformer, (L.E/kVA);
V_n	nominal voltage of TL, kV;
$\Delta V, \Delta V_\ell$	maximum voltage drop in the point of connection and at load bus:
C_{rv}	the cost of transformer regulated voltage device, (L.E/kVA)
L_ℓ, C_ℓ	TL length and the cost of one km length, 10^3 $\$$/km;
ΔE_Σ	summation of energy losses, kWh
ΔP_Σ	summation of maximum power losses kW;
K'	the cost of selected network elements;
ν	coefficient of selected equipments combined utilization level ;
K_Q	the cost of reactive power installation compensation;
a	the cost of 1 kW of EPS to recover the loss, $\$$/ kW;
b_T	the expenses of conventional fuel on 1 kW/kg;
K_T	capital outlays on fuel and its transport per annume, $\$$

The value of demand factor K_d depends on the values of installed capacity (power) and its structures[1] .

$$K_d = f(P) \tag{14}$$

At the average level of electric power, the consumers are not utilizing maximum load.

$$T = 3000 - 3500\ h$$

Economical radius of distribution system is chosen as a function of P_o and distribution voltage [2]. As the initial data at determining economical regions of applied power take-off network, we take into account; distribution system of electrical energy (11-33 kV) Po kW/km^2, and economical radius of distribution network R_e ,km. The region of electrical power is considered in the from of a circle. The dimension of this circle is determined by the value of economical radius of distribution network R_e. Installed capacity of consumers is :

$$P = \pi R_e^2 P_o \tag{15}$$

The considered power of substation for this region of electric power;

$$S_o = \pi R_c^2 P_o K_c / \cos\phi_s \qquad (16)$$

The considerations are accomplished for $P_o = 0.5\text{-}5$ kW/Km^2 and $\cos\phi_s = 0.8$.

The values of installed power consumers and considered power take-off as a function of P_o at distribution network voltage 11-33 kV are recorded in table 1.

The component of capital charge K_Q produces an effect on selected installation at reactive power regime of TL. The selected installation with the capacitive divider voltage generates reactive power in TL. For improvement the regime of TL in this case, we must produce reactive power (compensation). According to the working regime of TL and type of voltage divider, this compensation may have positive or negative effect. In the first variant, we have economic facilities for compensation devices. But in the second, complementary charge of devices is required. Therefore, the charge component K_Q appears in Eq (13) with the two signals.

The reactive power generated by capacitive divider in line or consumption from it by inductive divider, may be computed by the following formula :-

$$Q_r = S_o[(K-1)V_c / V_k \pm \sin\psi] \qquad (17)$$

V_e equivalent selected voltage;
V_k voltage at compensation element circuit;
Ψ angle between load voltage and the current flow in compensated circuit.

The component of charge K_Q is determined by the cost of compensating device requirement :

$$K_Q = Q_r C_r \qquad (18)$$

Where : C_r : the cost of condensers and reactors.

Eq. (13) is suitable for calculating the different complete investments of selected circuit. Fig (3) shows the relation between the specific costs and the complete expenses of transformers and capacitive power take-off for line 220 kV. Figs (4&5) demonstrate the relationship between specific charges and load.density From these figures, large region utilized power take-off from TL 500 and 220 kV. Then , at $P_o \leq 3$ kW/ km^2 and the other electric power sources are faraway (> 30 km), capacitive take-off power at $V_e = 110$ kV is the economical efficient feeder. But at $P_o \leq 2$ kW/km^2 , the reactive power take-off is the best feeder.

Capacitive and reactive take-off at $V_e = 220$ kV may count rational feeders at $P_o \leq 4$ kW/km^{2}and the distance from the center of other sources is greater than 30 km.

Table 2 shows the considered cost of electrical energy C, 10^{-2} L.E/(kWh) and specific capital charges K_s ,L.E/ km^2. From this table , the economical indicators of take-off power at 33 kV are greater than at 11 kV.

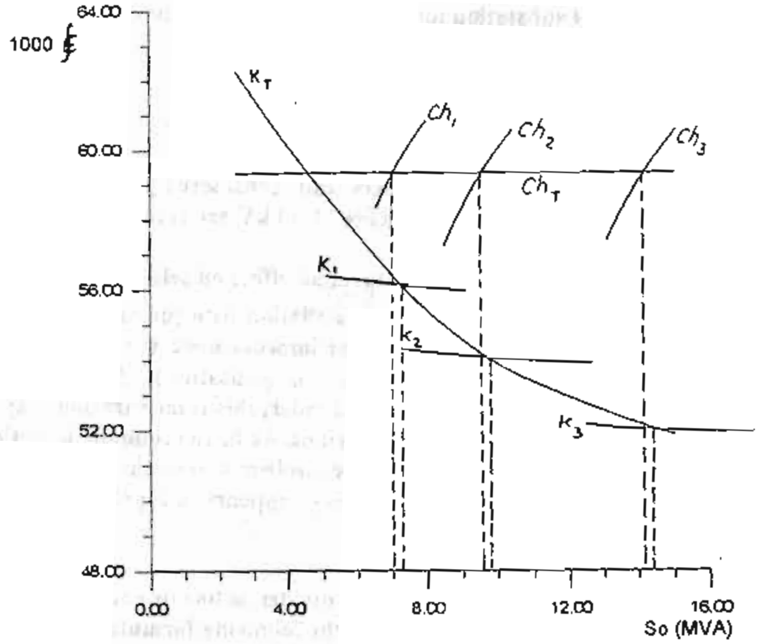


Fig.3 The Relationship Between the Charges(10^3 L.E) and Capital Cost of Transformer and Capacitive Take-off Power from 500 kV Lines.

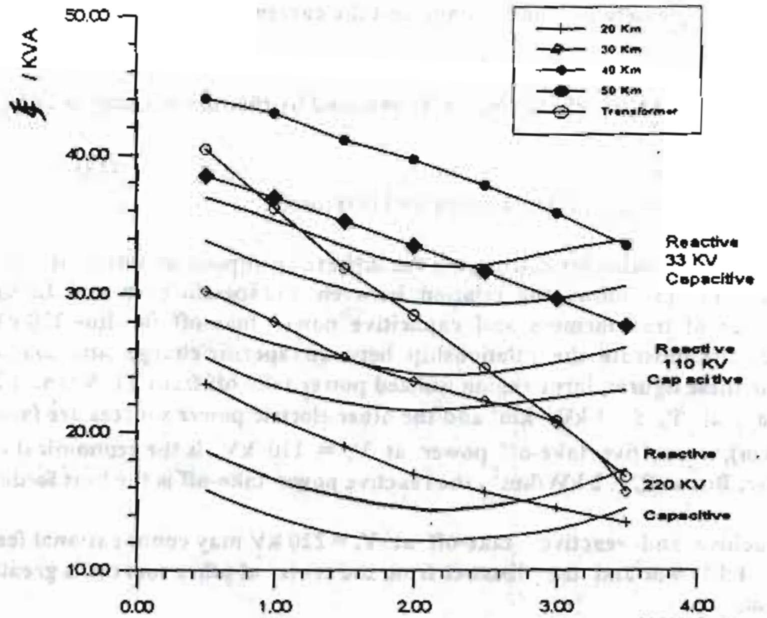


Fig.4 Specific Capital Costs of Site Passing HVTL (500kV).

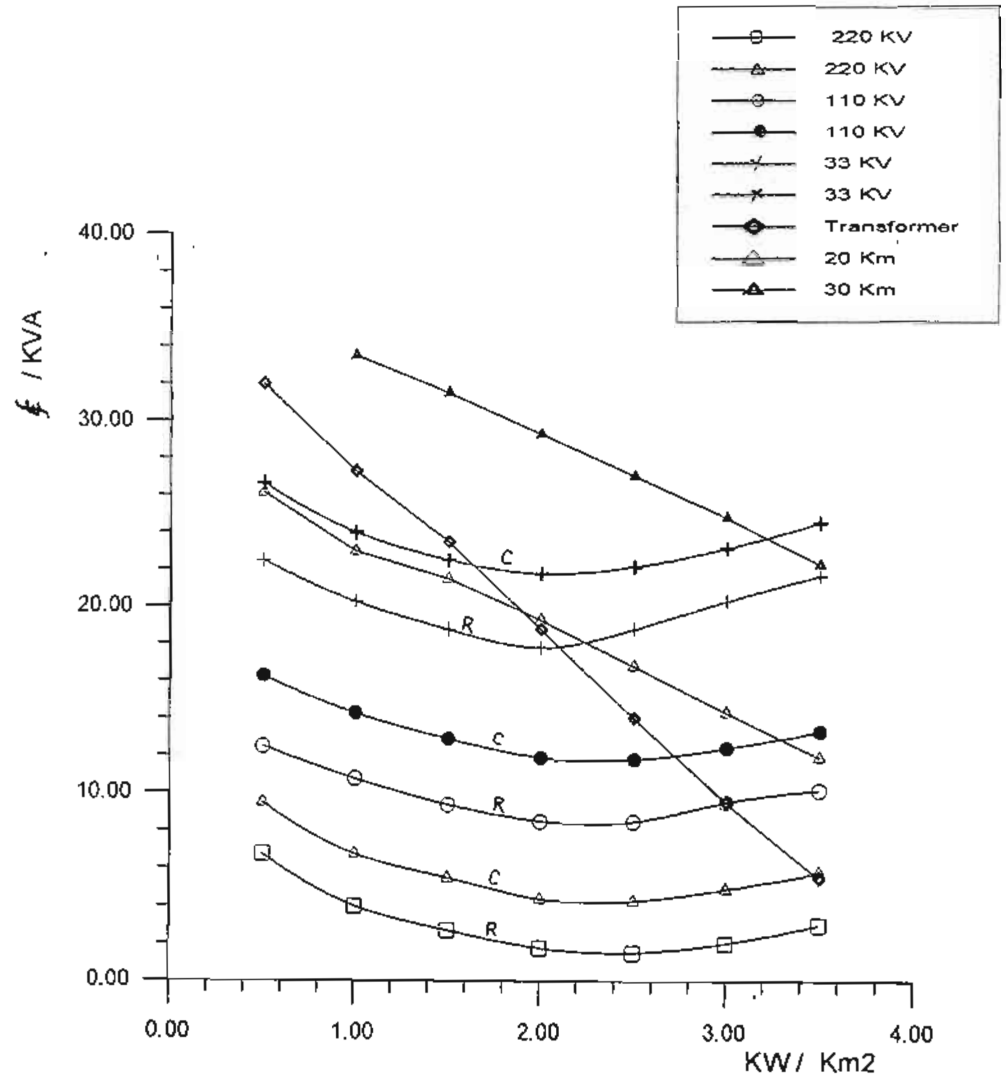


Fig.5 Specific Capital Investments of Electric Power 380 kV Passage TL.

CONCLUSIONS

(1) A suitable mathematical model is proposed and used as for capacitive as for inductive voltage divider. The short circuit across the compensating reactor of take-off power network decreases the over voltage at divider elements.
(2) As the economical criteria at chosen optimal variant may be specified as the complete expenses.
(3) At large distance from the system 110, 33 kV the power take-off is considered the best economical efficient source.
(4) Economical indicators of capacitive and inductive power take-off circuits are great at small voltage division factor.

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Table 1

V		P_o, kW/Km^2					
KV		0.5	1	2	3	4	5
11	R_c, Km	25	20	15	13	12	11
	P, kW	1100	1400	1600	1770	2000	2120
	S_o, kVA	680	760	830	940	1010	1080
33	R_c, Km	90	68	50	40	37	33
	P, kW	14200	16200	16800	17200	17500	19000
	S_o, kVA	7700	8200	8350	8420	8570	8900

Table 2

Electric power Circuit	Distribution Voltage KV	Surface Loads					
		1		3		5	
		C	K_s	C	K_s	C	K_s
Feeding Lines	33	0.74	62	0.5	89	0.43	133
	11	0.82	64	0.59	105	0.48	155
Selected transformers	33	0.78	68	0.63	97	0.52	145
	11	-	-	-	-	-	-
Capacitive take-off K= 500/110	33	0.8	76	0.64	106	0.53	168
	11	0.86	91	0.61	128	0.54	202
Inductive take-off K = 500/110	33	0.82	83	0.65	117	0.54	186
	11	0.89	101	0.7	143	0.59	224