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INTEGRATED-OPERATION OF PHOTOVOLTAIC POWER SYSTEM WITH EGYPTIAN POWER SYSTEM

تشغيل النظـام الفوتوفولتى مع النظام الكهربى المصـــرى

BY

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خلاصـه :

الهدف من هذا البحث هو دراسه تأثير التشـغيل المتوازى لمحطه القوى الشمسيه الفوتوفوليته مع الجـزء الشمالى من نظام القوى الكهربى المصرى • يتم دراسه تأثير ادخال مثل هذه النظم الجديده والمتجدده على جهـــد قضبان النظام الكهربى • وقد اجريت هذه الدراسه باستخدام طريقه من طرف سريان القدره• استخدمت هذه الطريقه بعد ان مثلت المحطه الفوتوفولتيه تمثيلا كهربيا على انها حمل سالب • وقد كانت جهود القضبان هى العناصر الـتى اجريت عليها الدراسه وذلك لمواقع متغيره على النظام الكهربى وقدرات مختلفه للمحطه الشمسيه • وقد روعى ان تكـون المواقع التى وصفت بها المحطه الشمسيه هى فى المناطق الصحراويه التى تعتبر امثل المواقع التى يتم وضع فيهـــا هذه المحطات وقد اجرى البحث لمعرفه التأثير على القيم الحقيقيه والتخيليه وايضا على القيم المطلقه لجهـــود القضبان التى تم ربط المحطه الشمسيه بها وايضا على القضبان الاخرى_ وقد اوضحت الدراسه ان ادخال المحطـــه الشمسيه الفوتوفولتيه فى نظام القوى الكهربيه له تأثير على القيم الحقيقيه والتخيليه لجهود القضبان وليس لها اى تأثير على القيم المطلقه لجهود القضبات المختلفه التى وصلت بها المحطه الفوتوفولتيه او غيرها •

ABSTRACT

The purpose of this paper is to research the effect of interconnection a photovoltaic power system PVPS with a power system on a bus voltage. This work is accomplished by using a modified Gauss-Seidel method. The modification presents PVPS as a negative load which means when a PVPS is connected . to a generator bus. and the real power generated from it must be added to the generated power. on the other hand if PVPS is connected to a load bus. the power generated from it is subtracted from the real power of this load. The study of this integration is programmed for various sites of PVPS on a power system. and for different sizes of PVPS. The results of this study show that the insertion of PVPS on a power system has a pronounced effect on theactive and reactive components of bus voltages.Besides. it has no effect on the absolute value of the buses voltages.

INTRODUCTION

Conversion of solar energy into electricity is very *important because it is a clean energy source. All countries in the world receive some solar energy depending on their sites. This amount is obtainable from a few hundred hours per year as in the northern countries and the lower part of South America, to four thousands hours per year as in the case in the most of Arabian countries and Sahara Desert. The area of natural deserts of the world is about $20*10^6 Km^2$ with average solar insolation $583.3W/m^2/day$ [1]. Another areas $30*10^6 Km^2$ receive about $291.65W/m^2/day$. The amount of solar energy received by land area (if we ignore all area of sea) $50*10^6 Km^2$ is $162.2*10^{12} Kwh/day$, assuming eight hours of sunshine, or $60*10^{15} Kwh/year$. Using 5% of this energy will result in energy of $300*10^{13} Kwh$ and comparing this with the estimated world energy demand in year 2000 is $50*10^{12} Kwh/year$, it can be seen that it is 60 times what the world will require then [1].*

A stand-alon photovoltaic power system consists of photovoltaic arrays, power conditioner and an energy storage. The energy storage is very important equipment in photovoltaic power system. It is used to store solar energy and as a maximum power traking element. A brief background on the preparation of standard energy storage equipment is existed in four standard documents prepared for large lead storage batteries. These documents are used to prepar batteries at power stations , substations and PVPS [2].

A method for determining optimum point of design PVPS is based on the coupling of the load to the solar cells arrays by means of a two - port with a transfor . This method enable one to contruct a more efficient and reliable solar cells arrays together with the most suitable storage system in order to assure better operation of a solar electrical system.[3].

A photovoltaic power system PVPS may be operated outside the atmosphere in the space as a solar power satelite. The transmission of a solar power satelite energy to the earth's electric power systems is carried out by means of microwave technology and interface systems [4].

Because of the dispersed and intermittent nature of solar photovoltaic energy system, the interconnection scheme is the most appropriate in a major concern. The discussion of integration issues in a point of view economic and a comparison between three schemes of integration of PVPS to the utility are prepared. These schemes are a) PVPS with complete utility-back and back up, b) PVPS with utility storage and c) PVPS with residential storage [5].

This paper presents the interconnection of a PVPS to the northern Egyptian electrical power system Fig.1. The effect of this interconnection when PVPS acts as a real power source is studied.

PROBLEM DISCRIPTION

A problem here is study of an interconnection of photovoltaic power system with the North part of Egyptian power system. A study is handeled in a point of view the effect on a system buses voltages. A bus voltage can be written in the form of $V = A + jB$ and its absolute value is $|V|$. The effect of interconnection of PVPS on A, B and $|V|$ is investigated. The study is accomplished by using method of load flow and a mathematical model of PVPS. The PVPS is operated at a maximum

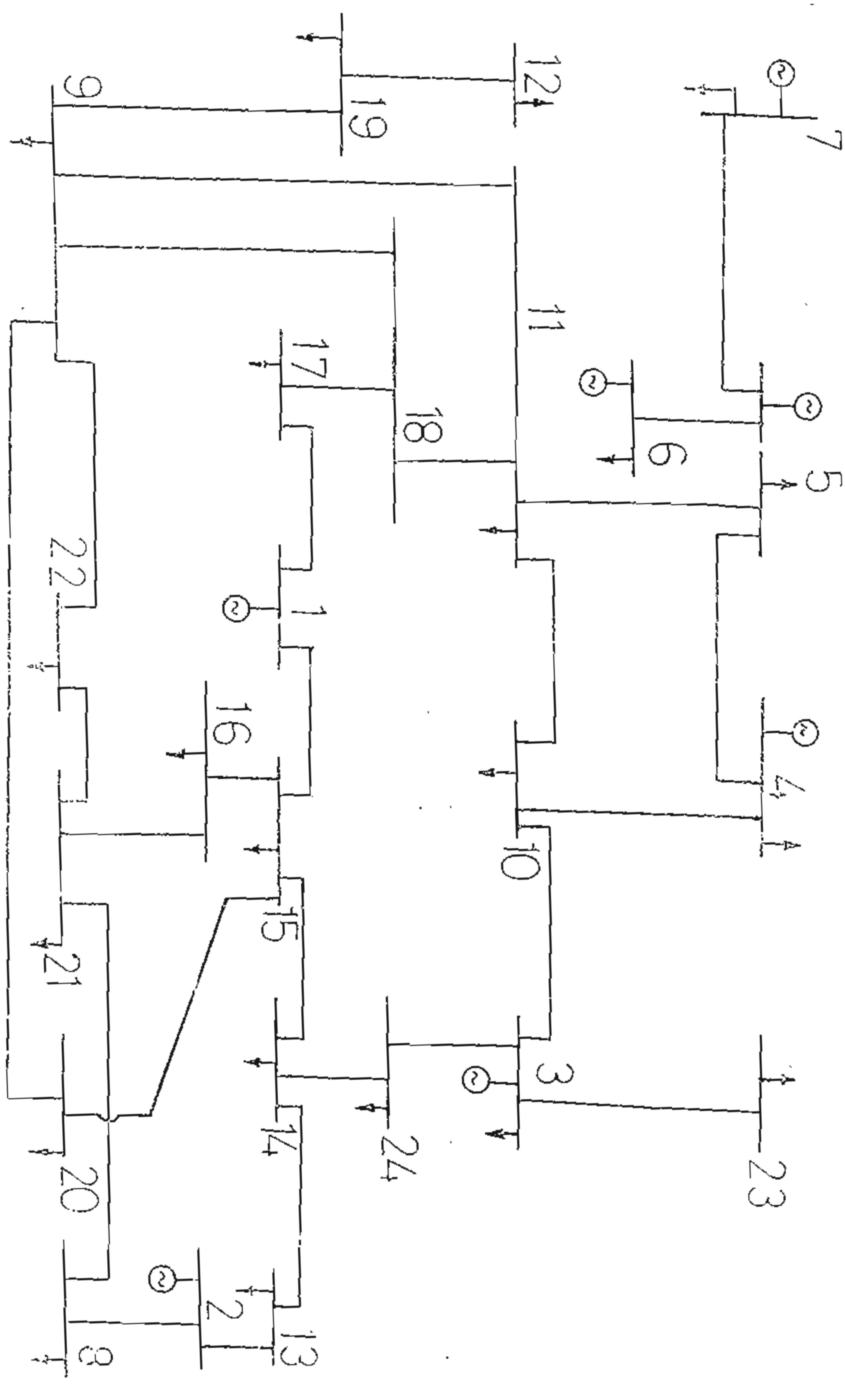


Fig.1 North Part of Egyptian Power System

power point with a conversion efficiency of 10%. The north part of Egyptian power system consists of 24 buses. It has 6 generator buses and the others are load buses. A photovoltaic power system PVPS is interconnected with some of generators and load buses.

MATHEMATICAL MODEL OF PHOTOVOLTAIC POWER SYSTEM

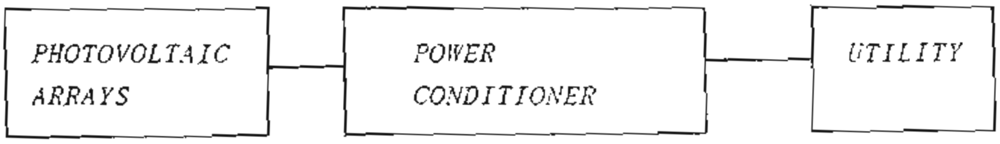


Fig.(2) Photovoltaic Power System

Fig.(2) shows a solar photovoltaic energy system which is connected with a utility. consists of photovoltaic arrays (PVA) and power conditioner. The solar cells arrays consists of modules are linked together in a series or parallel or in series parallel compination as shown in Fig.3.

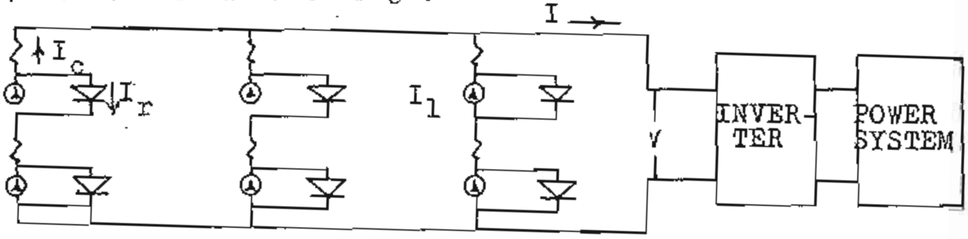


Fig.3 Series parallel combinations of the solar cells

The output current of a cell I_c *is a function of photocurrent* I_L*, reverse saturation current* I_r*, cell voltage and its series resistance [6]*

$$I_c = I_l - I_r \left(\exp((I_c R_s + E_c)\, q / A_o K T) - 1\right) \qquad (1)$$

where

q is the electron charge

A_o *factor depends on solar radiation*

K Boltzman's constant

T cell temperature

$$I_l = \frac{I_{sc} \left(\exp(E_{oc}\, q / A_o K T) - 1\right)}{\left(\exp(E_{oc}\, q / A_o K T - \exp(I_{sc} R_s\, q / A_o K T)\right)} \qquad (2)$$

E_{oc} *cell open circuit voltage*

I_{sc} *short circuit current*

$$I_r = I_{sc} \left(\exp(E_{oc}\, q / A_o K T) - \exp(I_{sc} R_s\, q / A_o K T)\right)^{-1} \qquad (3)$$

$$A_0 = 1.95 + .02\ I_h \qquad (4)$$

I_h intensity of solar radiation on horizontal surface

The output current of a solar cells array is.

$I = I_c * N_p$

Output voltage of the array is.

$V = E_c * N_s$

Where

N_p = number of parallel moduls

N_s = number of series moduls

Output power of the array is.

$P = V * I$

The voltage and current at a maximum power point are.

$$E_{mp} = D_1 - D_2 \ (T_c - D_7 \ ) + D_3 \ \log I_h$$

$$I_{mp} = D_4 \ I_h + D_5 \ (T_c - D_1 \ )$$

Where $D_1, D_2, D_3, \ldots D_7$ are a cell coefficients

$P_m = E_{mp} * I_{mp}$

P_m power at a maximum power point from a cell

$$P_{ma} = P_s = E_{mp} * I_{mp} * N_p * N_s \qquad (6)$$

$P_{ma} = P_s$ power output from the array operats at maximum power point

The inverter efficiency is taken as 95%

LOAD - FLOW STUDY

The load flow study is accomplished by using Gauss -Seidel method using Y_{bus}. A photovoltaic power system is considered as a negative load. By using this assumption Gauss - Seidel method can be used for solving load flow problem . As a PVPS is connected to a load bus it's power is subtracted from the load power connected to this bus. While it's power is added to the generator power which connected to a generator bus. For all buses except slack bus [7].

$$I_p = S_p^* \ / \ V_p^*$$

$$I_p = \sum_{q=1}^{n} Y_{pq} \ V_q \qquad p = 1, 2, 3, \ldots n, \quad p \neq s \qquad (7)$$

Where

S_p = power at bus p

$= (P_p - P_s) - j\, Q$

P_p active power injected to bus P from PVPS

P_s active power injected to bus P from PVPS

Y_{pq} admittance between bus P and q

V_q voltage of bus q

$$V_p = 1 / Y_{pp} \left(S_p^* / V_p^* - \Sigma\, Y_{pq} V_q \right) \quad p = 1, 2, 3, \ldots n,\; p \neq q \qquad (8)$$

The iterations by using Gauss - Seidel method as a PVPS connected to a bus P is defined as

$$V_1^{k+1} = 1 / Y_{11}\left((P_1 - j Q_1) / V_1^{k*} \right) - Y_{12} V_2^k - Y_{13} V_3^k \ldots\ldots$$
$$Y_{1q} V_q \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Y_{1n} V_n^k)$$

$$V_2^{k+1} = 1 / Y_{22}\left((P_2 - j Q_2) / V_2^{k*} - Y_{21} V_1^{k+1} \ldots\ldots - Y_{2n} V_n^k \right)$$

$$V_p^{k+1} = 1 / Y_{pp}\left((P_p - P_s - j Q_p) / V_p^{k*} - Y_{p1} V_1^{k+1} \ldots Y_{pp-1} V_{p-1}^{k+1} \right)$$

$$V_n^{k+1} = 1 / Y_{nn}\left((P_n - j Q_n) / V_n^{k*} - Y_{n1} V_1^{k+1} \ldots\ldots\ldots Y_{nn-1} V_{n-1}^{k+1} \right) \ldots (9)$$

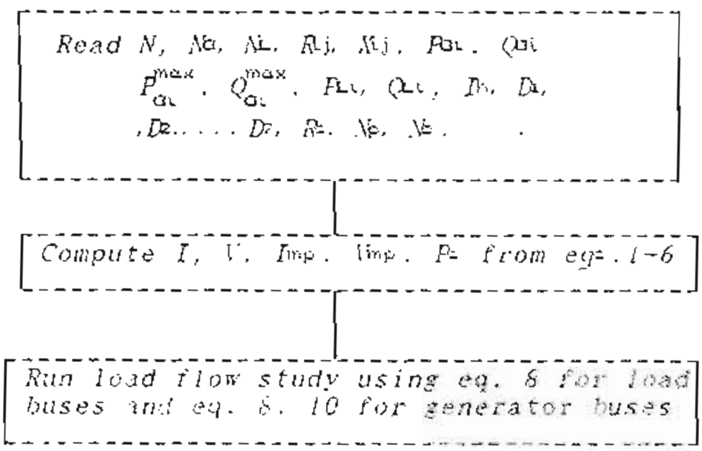
Where K is the iteration number

In this study a PVPS may be connected to a load or generator bus. At a P-V bus a real power injected from PVPS is added to that generated from a generators connected to this bus. The reactive power Q is not specified at such a bus. The voltage magnitude must be held at the value

$|V|_p^{sp}$. Because of equipment limitation, Q_p can vary between Q_p^{max} and

Q_p^{min}. At P-V bus, Q_p^{sp} is replaced by Q_p^{cal} during the computation.

FLOW CHART



Write the results

Fig. 4 Flow chart for solving Load- Flow problem

Where,

N total number of buses
N_G number of generators
N_L number of load buses
R_{ij}, X_{ij} resistance and reactance of line ij
P_{Gi}, Q_{Gi} active and reactive power generated from generator i
P_{Li}, Q_{Li} active and reactive power demand by a load connected to bus i
solar cell efficiency
inverter efficiency

The solar photovoltaic power sstem is connected at bus numbers 6,11,19 and 24. Where bus 6 is a generator bus. buses 11,19 and 24 are a load buses in desert. A load flow study is carried out firstly without PVPS. In the next stage a study is carried out with PVPS connected to bus number 6.11.19 and 24 respectively.

This study is carried outinstantinouslly for each hour during a sunshine period and for different sizes of a SPVPS ,1Km^2,3,5.7.9 and 11Km^2.

The results of this algorithm are a family of curves for the variation of buses voltages, at which PVPS is connected. and for a different size of solar cells array.

RESULTS

The calculated results of a program are shown in figs. 5 to 8. Fig.5 represents the relationship between active and reactive components of bus voltages A and B of voltage of a bus number 6 at which SPVPS is connected. Bus 6 is a generator bus and SPVPS is connected and operate in parallel with a power station connected with this bus. A variation of reactive component (B) of bus voltage in per unit, the base voltage is 220Kv. against time is shown in the upper part. The dashed line represents B against time when SPVPS is disconnected from a bus. A family of curves are represents B for different sizes of solar cells array. These curves are function of time and is similar to the variation of insolation against time. This means that B is increased with time and reached to a maximum value at a noon instant a bottom decreased. In the opposite direction A (active component of generator bus 6) is varied with time. The variation of(A) decreases with a large rate of change than (B). then decreases and reach to minimum value at a noon instant.

Bus 11 is a load bus in which load 0.0324 pu (base MVA=500) and PVPS is connected at this bus. Fig,6 represents the variation of reactive and active components of bus voltage versus time. In these curves a variation of (B) is similar to the variation of insolation against time. It increases and reach to a maximum value at noon instant. Active component (A) takes an opposite variation of (B). It decreases with time and reach to a minimum value at a noon instant.

When PVPS is connected at buses 19 and 24 respectively. The variation is similar to that in fig.5. But in fig.6 a variation of (A) versus time take the proporities of generator and load buses. It is due to that the bus site is far away from generator buses.

The effect of insertion PVPS on the absolute values of buses voltages is illustrated in fig.9. It has been shown that the insertion of a PVPS has no effect on the absolute valus of buses voltages. This is due to the fact that PVPS is a source of real power only.

CONCLUSIONS

In this paper a photovoltaic power station (PVPS) is interconnected with a power system The effect of interconnection on a bus voltage at which PVPS connected is studied. A PVPS is connected with a generator and load buses. The study shows that its effect in a generator bus is opposite to that effect when its connected to a load buses. This means that PVPS which is a source of active power only may be integrated with electrical network. The effect of it in a bus voltage at which interconnected is no longer pronounced. This due to the opposite rate of change of active and reactive components of bus voltages. This means that the insertion of PVSPS at any bus of a power system has no longer effect on a bus voltage magnitude.

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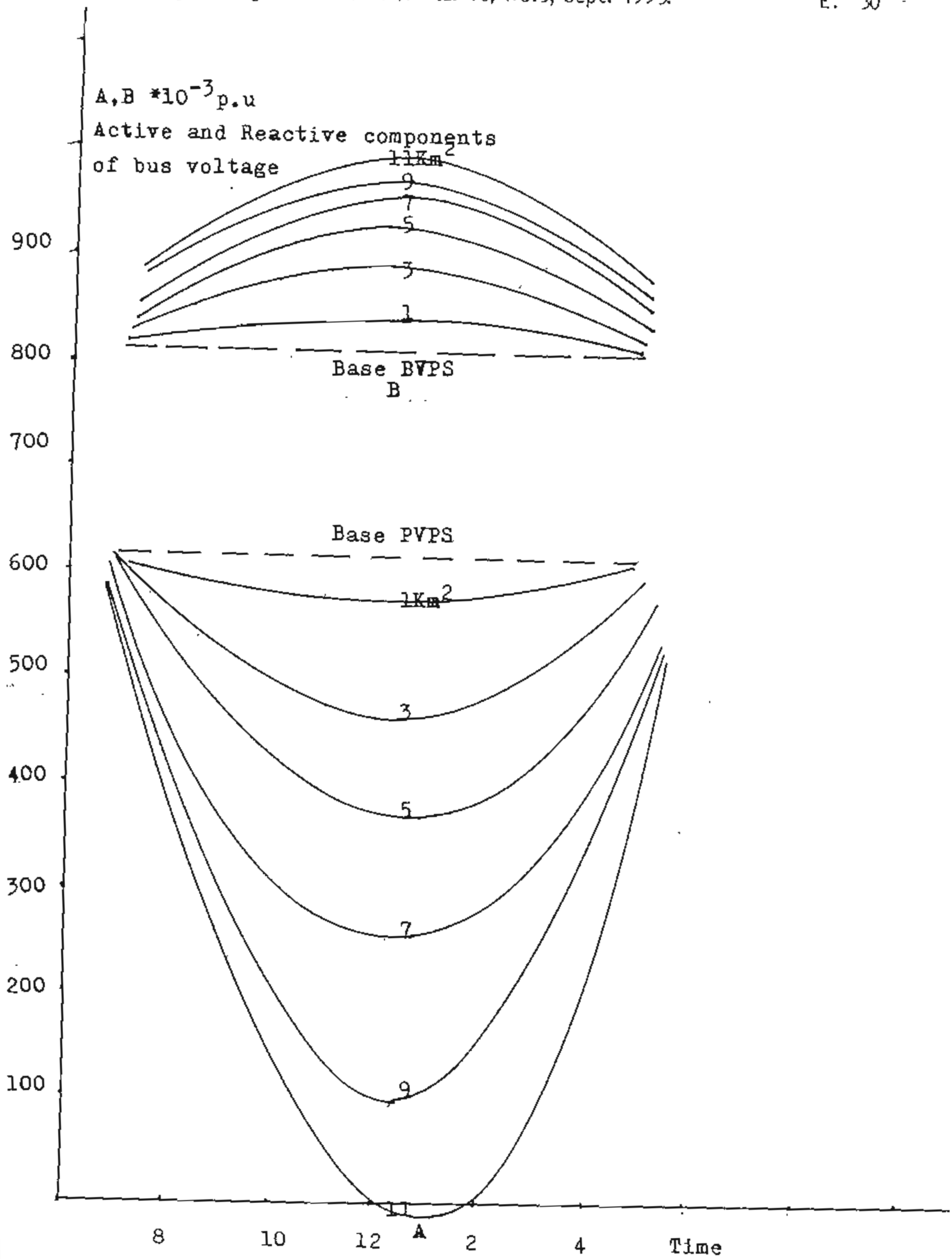

Fig.5. Variations of Active and Reactive Components of a Generator bus Voltage No.6 Which is connected with a Photovoltaic Power Station with different sizes.

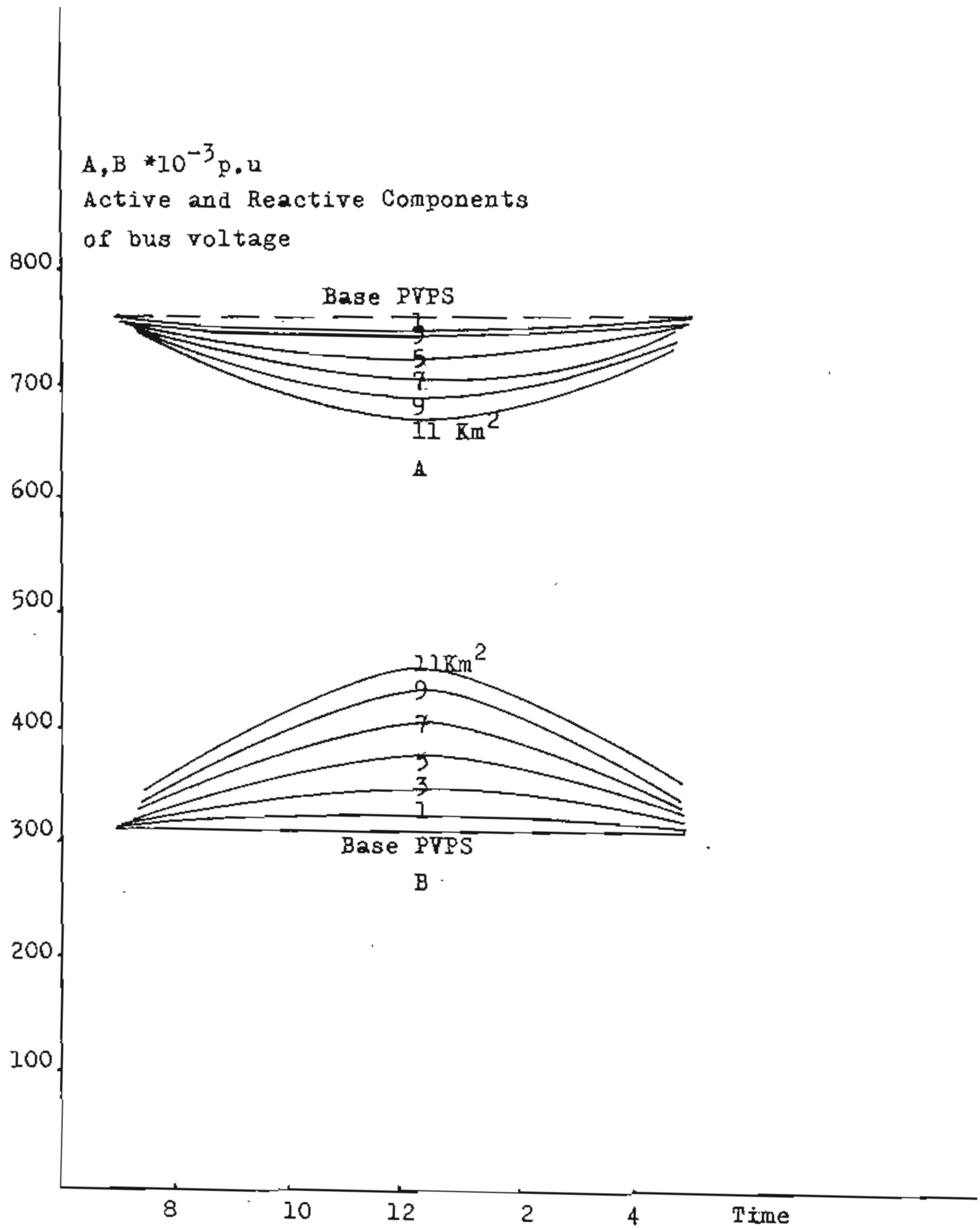

Fig.6. Variations of Active and Reactive Components of a Load bus Voltage No.11 Which is connected with a Photovoltaic Power Station with different sizes.

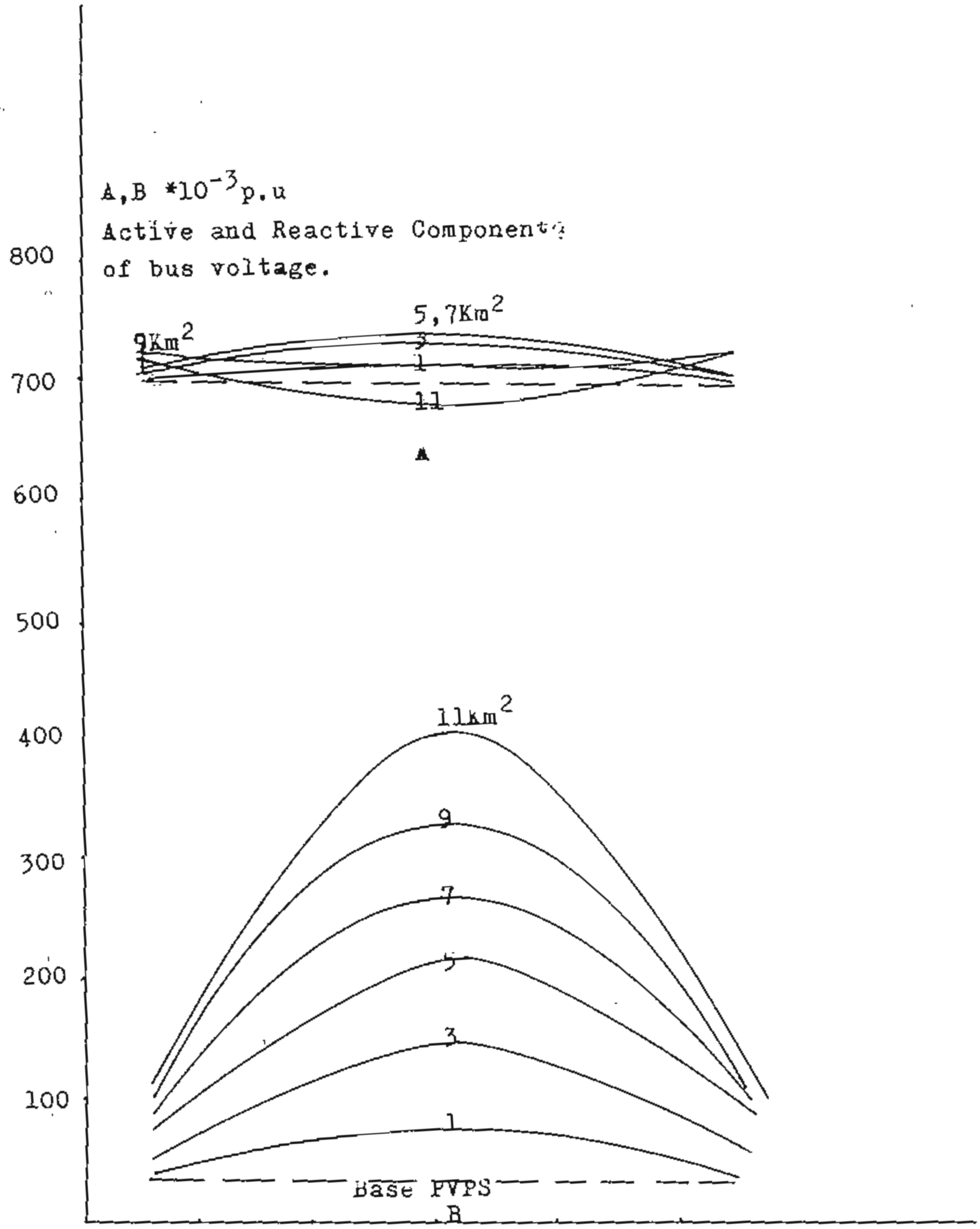

Fig.7. Variations of Active and Reactive Components of a Load bus Voltage No.19 Which is connected with a Photovoltaic Power Station with different sizes.

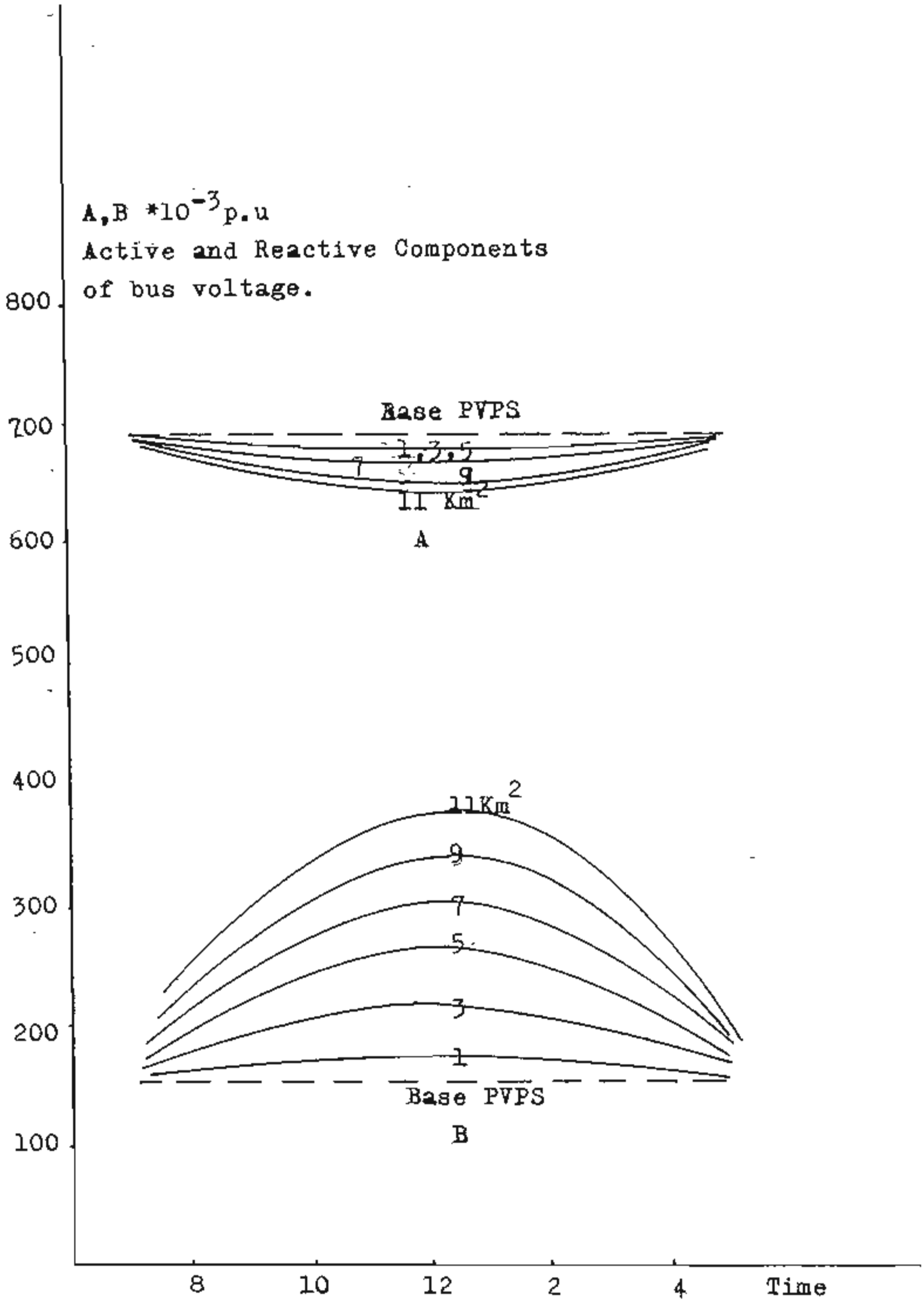

Fig. 8. Variations of Active and Reactive Components of a Load bus Voltage No.24 Which is connected with a Photovoltaic Power Station with different sizes.

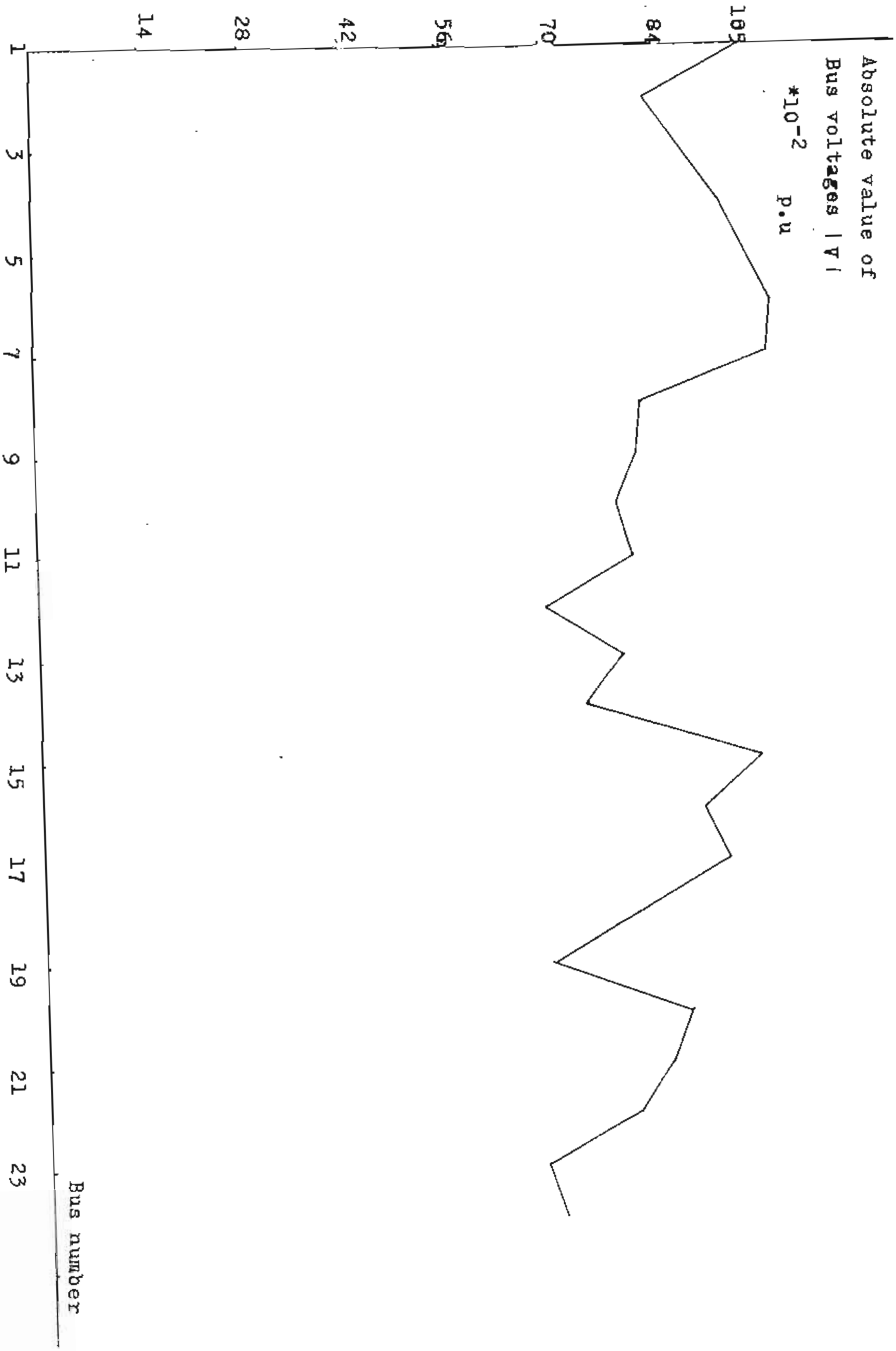

Fig.9 Buses voltage for all positions and sizes of PVPSS