Analysis of parallel connection of Rosen type piezoelectric transformers

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***Abstract* - Single layer Rosen type piezoelectric transformer is an attractive component for portable high voltage applications because of its small thickness and low cost. It is favorable for applications such as LCD backlight cold cathode fluorescent lamp converters where thickness is an important feature. In general piezoelectric transformer can produce low output power only and this is a major drawback in many applications where more power is needed. A promising solution is parallel connection of several transformers. In this paper parallel connection of piezoelectric transformers is investigated and discussed. A simple model is produced which allows representation of characteristics of parallel Rosen type piezoelectric transformers. Comparisons with experimental result verify the model. This model provides engineers with a simple and useful design tool.**

I. INTRODUCTION

The small thickness, simple structure, low cost and high step up ratio of Rosen type piezoelectric transformer attracts a lot of attentions for usage on the backlight power converters of portable computers and hand held devices. [1, 2]

Piezoelectric transformer (PT) has some drawbacks as a power conversion component. The piezoelectric transformer characteristics tend to drift with operating conditions. The operation point should be well controlled in the resonant region in order to have maximum efficiency and output power [6]. Conventional AC equivalent circuit of Rosen type piezoelectric transformer can only emulate the relationship between voltage gain and driving frequency, but it is not sufficient to emulate the relationship between voltage gain and a wide load range. This is solved by an improved model for Rosen type piezoelectric transformer [3] which is used in this paper. It provides modeling of the output characteristic within a wide load range. In this paper, we base on that improved model [3] and simplify the calculation by an "Effective Parallel Factor" to represent the parallel connection characteristic. Another drawback of piezoelectric transformer is the low output power. Most piezoelectric transformers can only handle very low power down to a few watts. The multi-layer piezoelectric transformer is a way to solve the problem but the fabrication techniques are complex and the cost is high. [1, 2, 4]. Low output power is becoming a major handicap of piezoelectric transformers as LCD becomes bigger and bigger and more power is demanded.

Parallel connection of piezoelectric transformers provides a method to increase output power. This paper presents an analysis on parallel connection of Rosen type piezoelectric transformers. The present work discovers that paralleled piezoelectric transformers can produce higher output power but not in a linear trend. A parameter is proposed to add on the improved model that provides the characteristics of parallel piezoelectric transformers. Merits and drawbacks of paralleling piezoelectric transformer are analyzed through the experiments and the improved model [3].

II. MODELING OF PIEZOELECTRIC TRANSFORMER

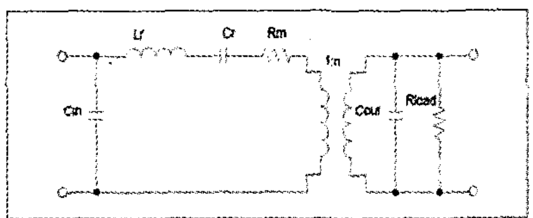

Figure 1. Conventional equivalent circuit of a piezoelectric transformer.

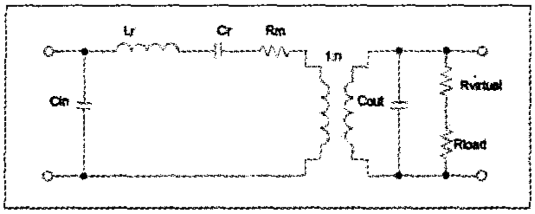

Figure 2. Improved model of a piezoelectric transformer

Figure 1 shows a conventional piezoelectric transformer model. [1, 2, 5] Its operation is based on mechanical resonance of the structure whereby electrical energy is produced through conversion of mechanical energy. It is modeled by a resonant circuit. However, results produced by this conventional model (Fig. 3) are not satisfactory and they do not match with measured results in most parts of the characteristics. This is because the conventional piezoelectric transformer models the frequency response at a certain operating point only. The model becomes invalid when different loads are applied to the model.

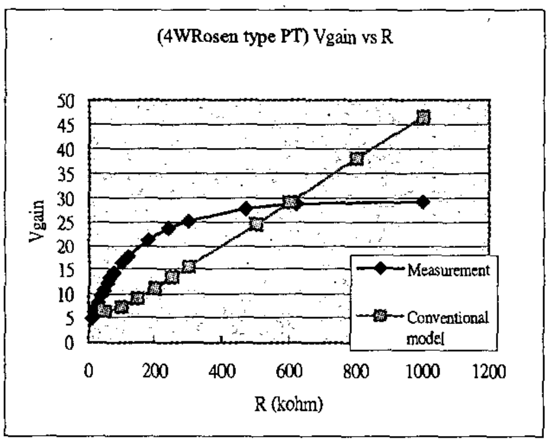

Figure 3. Voltage gain versus loading resistance→ Measurement of a practical Rosen type PT and the result from the conventional PT model.

An improved model shown in Figure 2 reflects the characteristic of voltage gain over a very wide load range. It is very simple in the sense that only one additional resistor is added in series with the load resistor. Comparisons between the measured and calculated results show that the Improved Model is better in this area [3]. The key equations for this additional resistor RV are shown below:

$$G2(x2) = \frac{x2}{R\lambda + x2}\cdot\sigma \quad (1)$$

$$G1(x1) = \frac{(\beta - \alpha)\cdot(x1 - R\alpha)}{R\beta - R\alpha} + \alpha \quad (2)$$

$$G2(RL) = \frac{RL}{R\lambda + RL}\cdot\sigma \quad (3)$$

$$RV(RL) = \frac{(-RL\cdot\sigma\cdot R\beta + RL\cdot\sigma\cdot R\alpha - R\alpha\cdot b\cdot R\lambda - R\alpha\cdot\beta\cdot RL + \alpha\cdot R\lambda\cdot R\beta + \alpha\cdot RL\cdot R\beta)}{(R\lambda + RL)\cdot(-\beta + \alpha)} - Rl \quad (4)$$

The parameters required in the Improved Model are extracted from the conventional model and from measurement data.

III. PARALLEL CONNECTION ANALYSIS

Here the parallel connected piezoelectric transformer characteristics is investigated. Figure 4 shows the different characteristics with parallel connection of piezoelectric transformers. The result is measured by an impedance analyzer HP4194.

Figure 5 shows a photo of the 4W single layer Rosen Type piezoelectric transformer used in this study. Measurement results in Figure 4 show that parallel connection increases the output power but the maximum is limited. The output power and the gain do not increase linearly with the number of piezoelectric transformers. Table A shows the Rosen type piezoelectric transformer has no further merits on the fourth and fifth parallel connection. This interesting pattern motivates the need to study the parallel capability of Rosen type piezoelectric transformer. Such information can be very useful for piezoelectric transformer converter design.

Work in this project shows that the single improved piezoelectric transformer model can be used to model parallel connected piezoelectric transformers. Base on the Improved Model, a Parallel Approximation Factor (PAF) is multiplied to the parameter σ.

The modified $R_{virtual}$ equation now becomes:

$$RV(RL) = \frac{(-RL\cdot\sigma\cdot PAF\cdot R\beta + RL\cdot\sigma\cdot PAF\cdot R\alpha - R\alpha\cdot b\cdot R\lambda - R\alpha\cdot\beta\cdot RL + \alpha\cdot R\lambda\cdot R\beta + \alpha\cdot RL\cdot R\beta)}{(R\lambda + RL)\cdot(-\beta + \alpha)} - Rl \quad (5)$$

The Parallel Approximation Factor can be observed by the small signal gain measurement from the parallel connection of the piezoelectric transformers. It is represented in equation (6). Where ρ is the voltage gain of the parallel-connected piezoelectric transformers with the secondary terminals opened. Parameter σ is the open secondary voltage gain of single piece piezoelectric transformer.

$$\text{PAF} = \frac{\sigma}{\rho} \qquad (6)$$

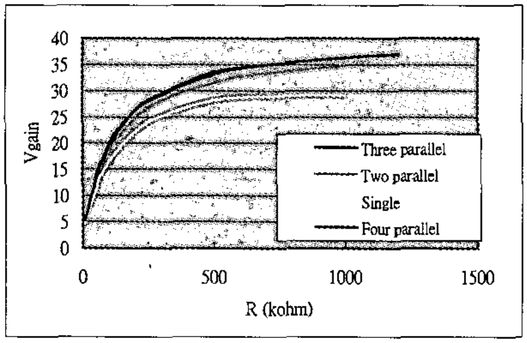

Figure 4. Output characteristic of different parallel number of piezoelectric transformers.

Figure 5. Photo of Rosen Type piezoelectric transformer used in this study.

This new improved method reduces model complexity by eliminating the need to add in many models in the analysis of parallel connection of piezoelectric transformers. The factor PAF greatly simplifies the model and prevents tedious mathematics. Moreover, this method produces results very close to practical measurements. This is because the PAF is obtained from calculation between measurement and observation. Hence, piezoelectric transformer converter design can be carried out much easier.

Figure 6 shows comparisons between measurements and calculation results using the improved model with PAF. It indicates this method can closely represent measured data obtained from paralleling the piezoelectric transformers.

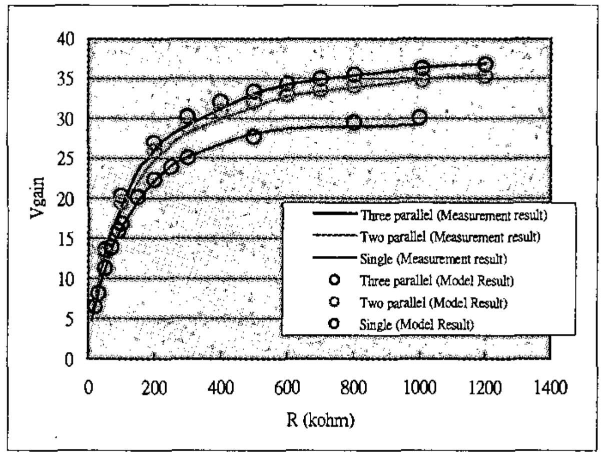

Figure 6. Comparison between measurements results and PAF modified model calculation results.

In order to clearly represent the parallel capability of Rosen Type piezoelectric transformers, another factor Parallel Availability (PA) is defined to show the benefit of further parallel connection. The larger the factor PA, the better the parallel connection performance. Zero PA means there is no more advantage with this number of parallel piezoelectric transformers.

The definition of PA is:

$$PA_N = PAF_N - PAF_{N-1} \qquad (7)$$

Table A shows the PAF and PA we used in this study.

Parallel connection?	No. of PTs	PAF	PA
No	1	1	
Yes	2	1.156	0.156
Yes	3	1.203	0.047
Yes	4	1.204	0.001
Yes	5	1.204	0

Table A. PAF and PA value.

Table A shows that piezoelectric transformers used for this study is limited to around three. Any number more than three does not produce corresponding increase in performance. This table provides a quick and clear way to characterize the performance of parallel connected piezoelectric transformers.

IV. CONCLUSIONS

Single layer Rosen type piezoelectric transformer is an attractive component for portable high voltage applications of its small thickness and low cost. Parallel connection of piezoelectric transformers is a good way to increase the output power and step up ratio. In this paper, two parameters PAF and PA are introduced to a model which models the performance of parallel connected Rosen type piezoelectric transformers. Moreover, the factor PAF becomes a protocol that can be used directly in an Improved PT Model and construct the performance graph for single or paralleled piezoelectric transformers. Experimental verification results are presented which show the accuracy of this method.

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