SINGLE PHASE VOLTAGE CONTROL USING SWITCHED INDUCTOR-SWITCHED CAPACITORS VARIABLE SUSCEPTANCE

Abdul-Kareem M. Obayis
University Of Babylon, College of Engineering, Department of Electrical Engineering

Abstract

Almost smooth phase voltage control with real time is adopted here. The basic controlling parameter is a pure capacitive or inductive susceptance. if the input phase voltage is below its rated value, then the susceptance is purely capacitive and its value is set such that it can raise the load voltage to the desired rated value. If phase voltage is above the rated value, then the susceptance is purely inductive and its value is set such that it can reduce the load voltage to its rated value.

The controlling process is completed within less than one cycle of phase voltage waveform. The overall associated error is less than three percent.

Introduction

Along the history of electrical development, there are a lot of techniques to control the terminal voltage (i.e. making it fixed at specified value). These techniques are either for controlling **DC** voltages or **AC** voltages. The **AC** voltage control techniques are presented here.

One of these techniques is the tap changing transformer technique. [1, 3, 4, 5]

By changing the transformation ratio of the transformer, the voltage in the secondary side is varied and voltage control is obtained. This technique is the most popular form of voltage control at all voltage levels. The main disadvantage of this technique is the poor time response.

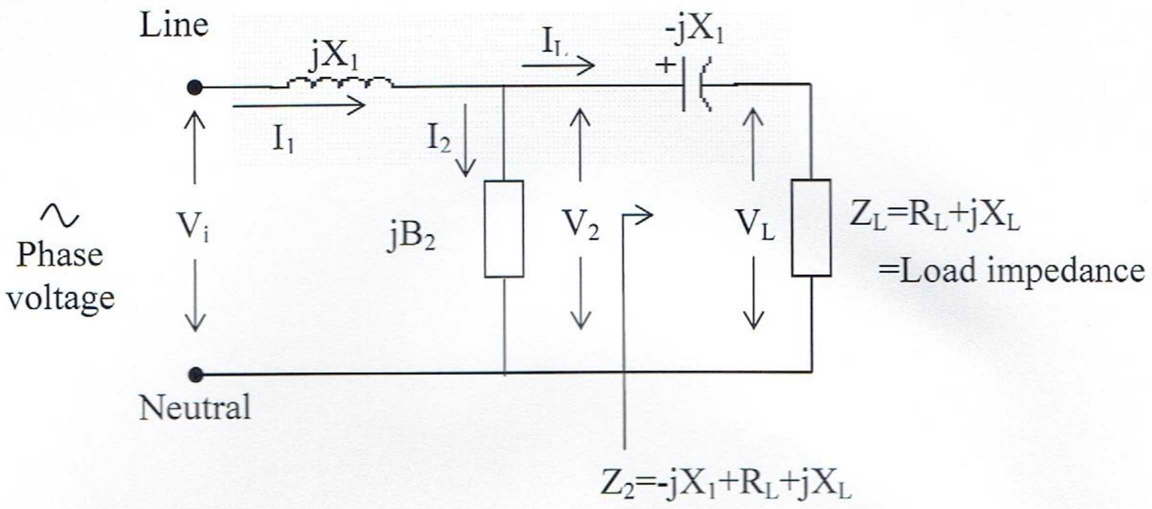
The injection of reactive power technique [2] is another one for controlling **AC** voltage. This technique is summarized by Injection of leading reactive power in busbar will tend to raise busbar voltage, while injection of lagging reactive power will reduce the busbar voltage. Static shunt capacitors, variable inductors, fixed inductors, and synchronous condenser are tools for generating or absorbing reactive power [2]. This technique is almost expensive and used for large systems.

Our proposed technique is a reliable one and is different from the techniques mentioned above and is stated clearing in the next section.

The Proposed Technique

Fig (1) shows the proposed system. Here $X_1 = wL_1 = \dfrac{1}{wC_1}$,

where w is angular frequency of the phase voltage in rad/sec, and $\boldsymbol{B_2}$ is a pure susceptance which is either inductive or capacitive depending upon the input voltage magnitude and load impedance. When the input voltage is less than the rated value of load voltage (i.e. $\mathbf{V_i} < \mathbf{V_{L\ \mathit{rated}}}$), then the load voltage may be not sufficient to operate the load efficiently, hence $\mathbf{B_2}$ must be purely capacitive and must have a value suitable for setting the load voltage at its rated value ($\mathbf{V_{L\ rated}}$), as stated in the phasor diagram shown in fig (2a).



$\mathbf{I_i}$ = Input phase current
$\mathbf{I_L}$ =Load current
$\mathbf{V_i}$ =Input phase voltage
B = controlling susceptance.

Figure (1). The proposed system power circuit

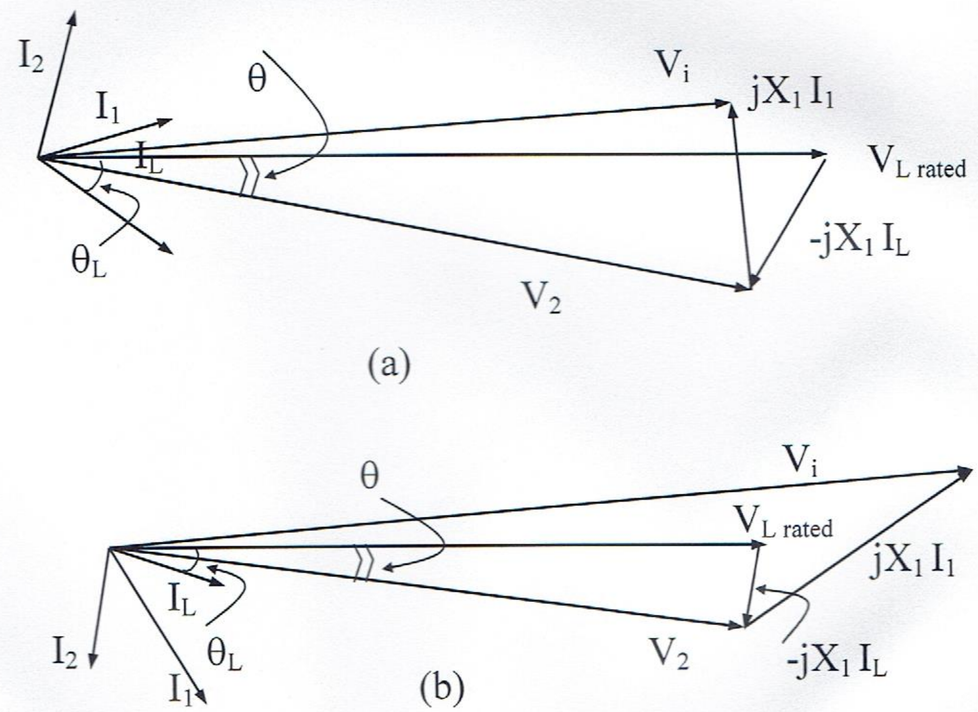


Figure (2) A phasor diagram (a) For $|V_i| < V_{L\ rated}$ and (b) For $|V_i| > V_{L\ rated}$

When |**Vi** |>**VL** rated, then $\mathbf{B_2}$ must be purely inductive and this case is stated in fig (2b). Looking at the phasor diagram, $\mathbf{B_2}$ appear as the major controlling quantity for fixing the load voltage at its rated value while the input phase voltage is fluctuating. For economical purposes and less losses, our technique suggests fixing the load voltage at its rated value while the magnitude of input phase voltage is varying in the range $\mathbf{V_{L\ rated} \pm 20\%}$.

The positive value of $\mathbf{B_2}$ means that the susceptance is capacitive whiles the –ve value means that the susceptance is inductive. A pure variable positive susceptance is obtained by a switched capacitor bank, while the negative susceptance is obtained by switching a single inductor and the unwanted or excessive inductive susceptance is cancelled by switching appropriate switched capacitors. Hence $\mathbf{B_2}$ is controlled in capacitive and inductive regions by the switched capacitors bank. For example if $|\mathbf{V_i}|$ is somewhat larger than $\mathbf{V_{L\ rated}}$ **,** then $\mathbf{B_2}$ must be inductive, hence the inductor **L** is switched to the power system and some of the switched capacitance must be switched to the power system in order to cancel the excessive inductive susceptance leaving only the required amount of inductive susceptance. Now if $|\mathbf{V_i}|$ is somewhat below the rated load voltage then $\mathbf{B_2}$ must be capacitive and only the appropriate switch capacitance are used while the inductor is kept off. If $\mathbf{V_i}$ is equal to $\mathbf{V_{L\ rated}}$ then $\mathbf{B_2}$ is zero and no switched capacitor or inductor is switched on.

Theory

Referring to the circuit shown in fig (1),we can write.

$$Z_L = R_L + jX_L = \sqrt{R_L^2 + X_L^2}\ \angle \tan^{-1}\frac{X_L}{R_L} = |Z_L| \angle \theta_L$$

$$Z_2 = R_L + jX_L - jX_1 = \sqrt{R_L^2 + (x_L - X_1)^2}\ \angle \tan^{-1}\frac{(X_L - X_1)}{R_L} = |Z_2| \angle \theta_2$$

$$I_1 = I_2 + I_L$$

$$V_2 = I_L Z_2$$

$$I_L = \frac{V_L}{Z_L} \quad \text{, and } I_2 = jB_2 V_2$$

$$Vi = V_L\left[1 - X_1 B_2 \frac{Z_2}{Z_L}\right] = V_L\left[1 - X_1 B_2 |Z| \angle \theta\right] \quad \text{...(1)}$$

$$\text{where } |Z| = \frac{|Z_2|}{|Z_L|} \text{ and } \theta = \theta_2 - \theta_L$$

Equation (1) can be rewritten as

$$\frac{V_i}{V_L} = \left[1 - X_1 B_2 |Z|(\cos\theta + j\sin\theta)\right]$$

$$\frac{|V_i|^2}{V_L^2} = (1 - X_1 B_2 Z\cos\theta)^2 + X_1^2 B_2^2 |Z|^2 \sin^2\theta$$

Here $\mathbf{V_L}$ is taken as a reference voltage.

In order that $\mathbf{V_L = V_{Lrated}}$, then $\mathbf{B_2}$ is found to be:

$$B_2 = \frac{1}{X_1|Z|}\left[\cos\theta - \sqrt{\frac{|V_i|^2}{V_{L\ rated}^2} + \sin^2\theta}\ \right] \quad \text{...(2)}$$

For small values of $\mathbf{X_1}$ compared to the rated load impedance ($|\mathbf{Z}_{L\ rated}|$), and for the magnitude of the input phase voltage in range of $\mathbf{V}_{L\ rated}$ **± 20%**, θ is small and $\sin^2\theta \approx 0$. Hence equation (2) can be approximated to:

$$B_2 = \frac{1}{X_1|Z|}\left[\cos\theta - \frac{|V_i|}{V_{L\ rated}}\right]$$

If $|V_i| > V_{L\ rated}$, then B_2 is negative or the susceptance is inductive, and if $|V_i| < V_{L\ rated}$, then B_2 is positive or the susceptance is capacitive.

Susceptance Computation

Since V_L is chosen as a reference voltage, then we can write the instantaneous load voltage as:

$$v_L = V_L\sqrt{2}\sin wt$$

$$V_2 = I_L Z_2 = \frac{V_L}{Z_L} Z_2 = V_L|Z|\angle\theta$$

Hence the instantaneous value of V_2 is:

$$v_2 = \sqrt{2}|VL||Z|\sin(wt+\theta)$$

if $\mathbf{v_2}$ is sampled at $wt = \pi/2$, then

$$v_2\big|_{wt=\pi/2} = \sqrt{2}|V_L||Z|\cos\theta$$

$$\text{or}\quad \cos\theta = \frac{v_2\big|_{wt=\pi/2}}{\sqrt{2}|V_L||Z|}$$

Z_L is computed as:

$$|Z_L| = \frac{|V_L|}{|I_L|}$$

Hence a voltage proportional $|\mathbf{V_L}|$ divided by a voltage proportional to $|\mathbf{I_L}|$ give $|\mathbf{Z_L}|$.
Note: $\mathbf{V_L}$, $\mathbf{V_2}$, and $\mathbf{I_L}$ are r.m.s. quantities
Also $\mathbf{Z_2}$ is computed as:

$$|Z_2| = \frac{|V_2|}{|I_L|}$$

Fig (3) shows the power circuit including the potential transformer used to compute $\mathbf{B_2}$.
changing $\mathbf{B_2}$ in sixteen levels and the error expected in setting the required value of $\mathbf{B_2}$ is $\frac{1}{32}\mathbf{B_{2max}}$. where $\mathbf{B_{2max}}$ is the maximum capacitive susceptance offered by the power circuit when all the four switched capacitor are switched on. Total capacitance is **15 C** and it must be switched on to the power system when the magnitude of the input phase voltage is $\mathbf{V}_{L\ rated}$ **-20%** (i.e. **0.8** $\mathbf{V}_{L\ rated}$) and in the same time the load impedance is purely resistive and equal to $|\mathbf{Z}_{L\ rated}|$. Note inductive load impedance requires less capacitive susceptance. The circuit shown in fig (5) is the control circuit and its operation is summarized as follows: The computed susceptance $\mathbf{B_2}$ is compared with zero reference. If $\mathbf{B_2}$ is positive, the output of the comparator is zero and the amplifier only amplifies $\mathbf{B_2}$ to a certain value suitable for the operation of the analogue to digital converter (**ADC**).

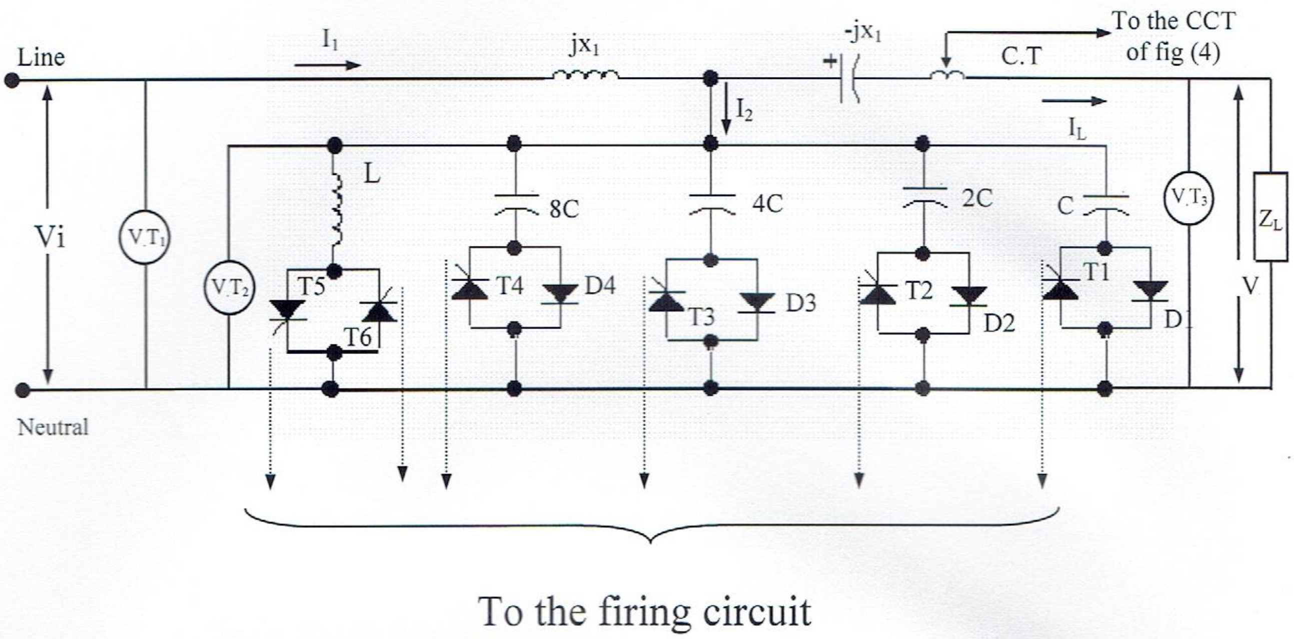
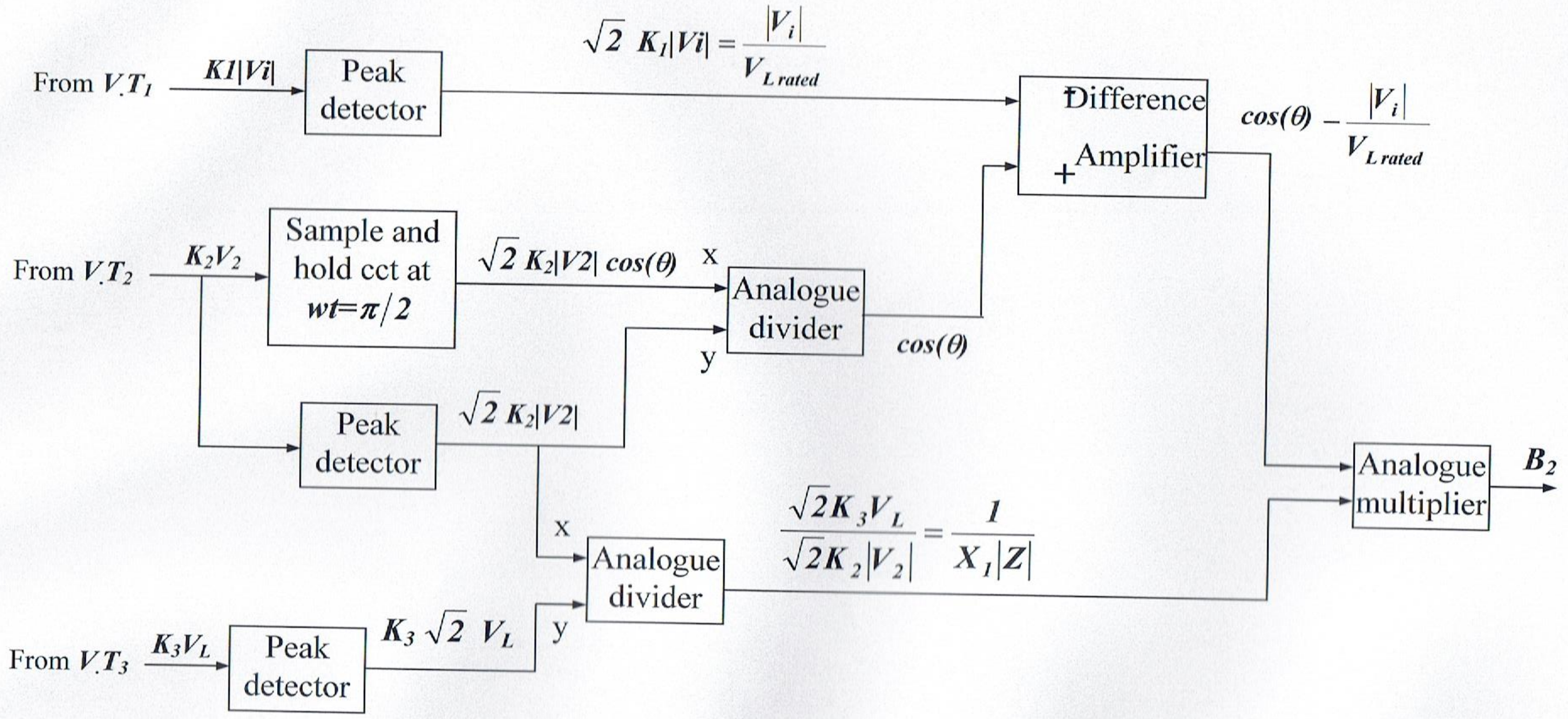


Figure (3). The power circuit of the proposed system

The output digits are used for triggering the Thyristors (T_1, T_2, T_3, and T_4) of the switched Capacitor bank. If B_2 is negative then the output of the comparator is 1 (i.e. **5** volts) and hence the Thyristor T_1 and T_2 are switched on injecting maximum inductive susceptance in the power circuit and hence the amplifier output voltage is a positive voltage proportional to the capacitive susceptance required to cancel the excessive unwanted inductive susceptance injected in the power circuit.



Here $\sqrt{2}K_1 = \frac{1}{V_{L\ rated}}$

and $\frac{K_3}{K_2} = \frac{1}{X_1}$

Note: K_1, K_2 and K_3 are constant and can be set to any specified value.

Figure (4). The susceptance computation circuit.

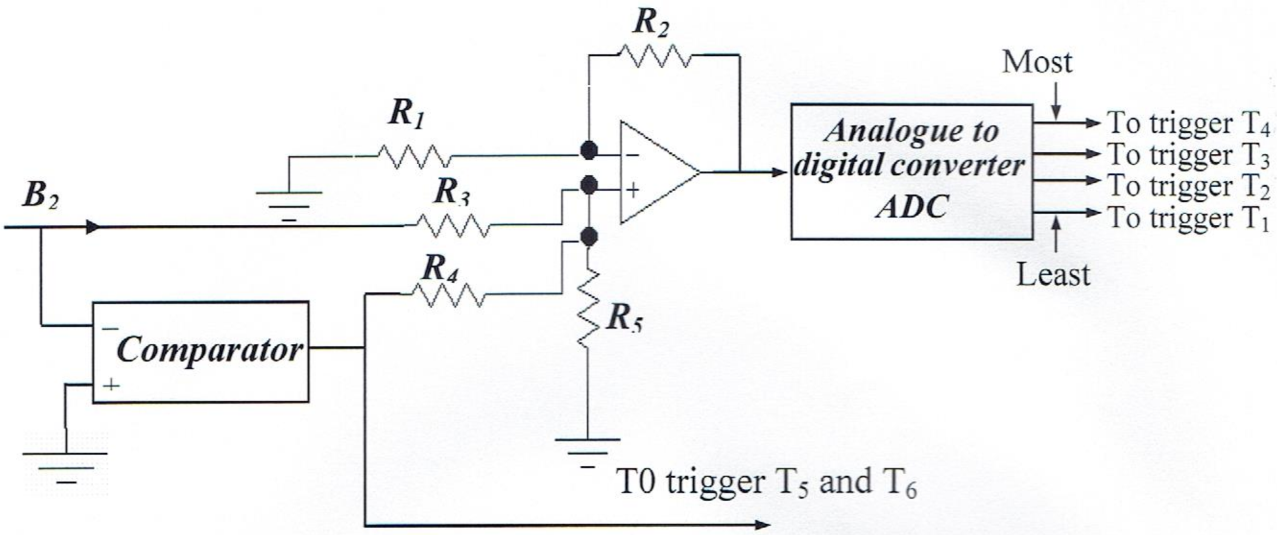


Figure (5) the control circuit of the proposed system

The Firing Circuit

The output of the **ADC** is used to trigger the Thyristors **T_1, T_2, T_3** and **T_4** while the output of the comparator is used to trigger **T_5** and **T_6** . Fig(6) shows the firing circuit of the proposed system. The **10KHz** square wave generator is used to generate a train of pulses suitable for the pulse transformers operation. Fig (7) shows the basic waveforms in the proposed system.

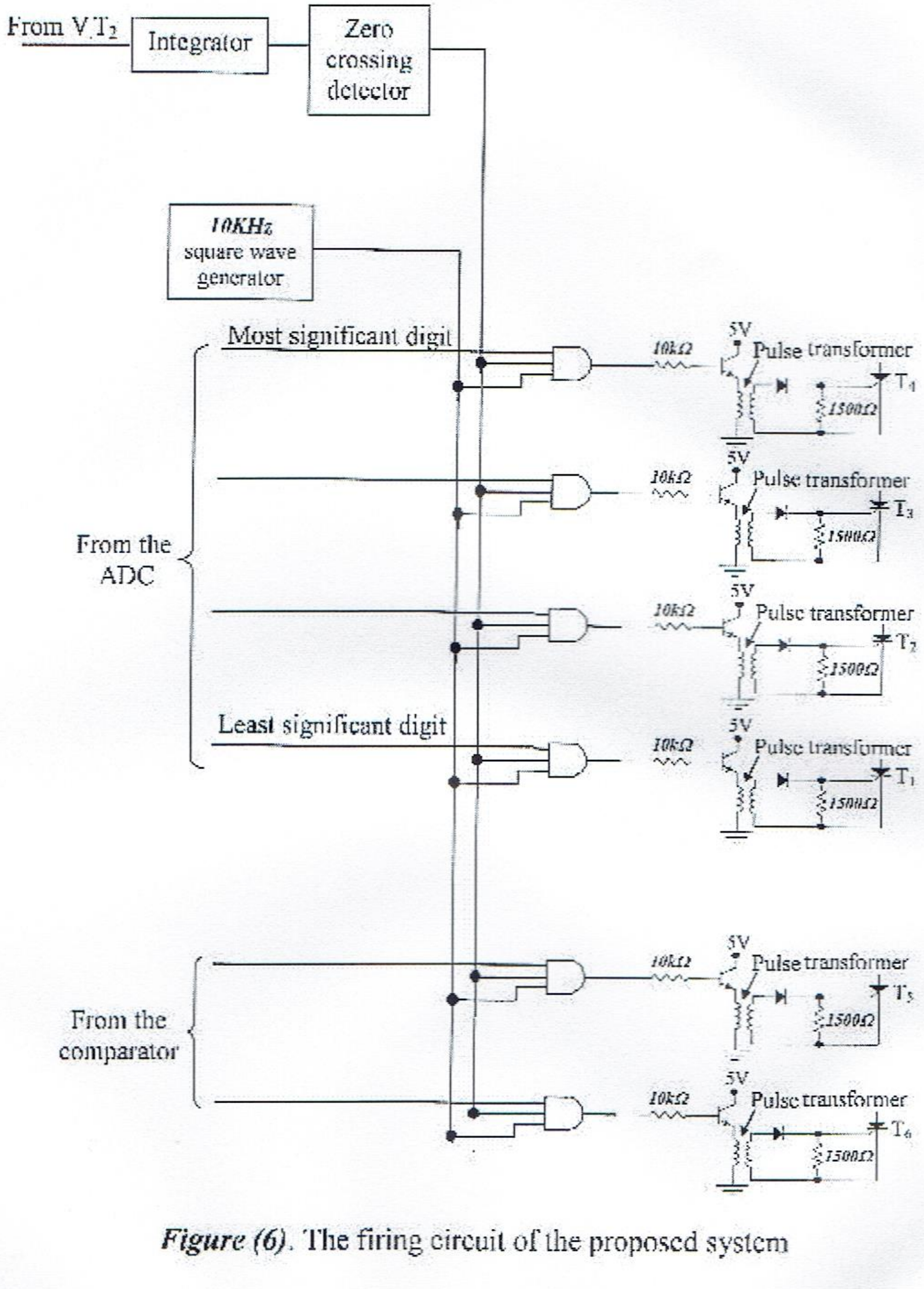


Figure (6). The firing circuit of the proposed system

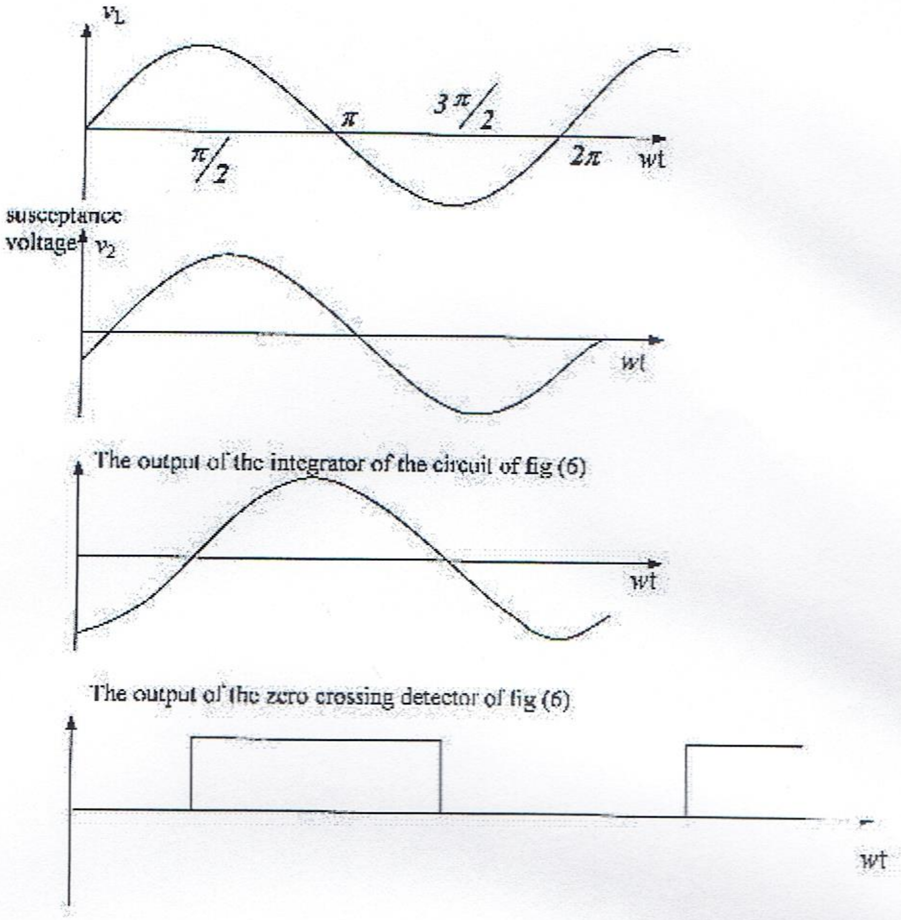


Figure (7). The important wave forms of the proposed system

Conclusion

The proposed techniques is characterized by:

1- Very fast response since the required susceptance is switched to the power circuit within one cycle of power system voltage waveform and the computation of the required susceptance is completed within less than one cycle.
2- The associated maximum error is less than 3% in the whole system.
3- High reliability.
4- The phase of the load voltage is somewhat closer to the phase of the input voltage.
5- Since the switched inductor and capacitor are switched on when the rate of change of v_2 is zero, then the output current and voltage are pure sinusoidal and hence no harmonic filter are needed.
6- The possibility of extension to three-phase system is available.

References

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السيطرة على الفولتية باستخدام مسامحة ذات محاثة ومتسعات مفتاحية

عبد الكريم مخيف عبيس
كلية الهندسة – جامعة بابل

الخلاصة

تم هنا تبني اسلوب سيطرة دقيق وآني على فولتية الطور الواحد المجهزة للحمل. العنصر المهم المستخدم في السيطرة هو مسامحة (susceptance) حثية او سعوية. اذا كانت فولتية الطور اقل من الفولتية القياسية للحمل عند ذلك سيتم اضافة مسامحة سعوية مناسبة الى الشبكة بحيث يتم رفع فولتية الحمل آنياً الى القيمة القياسية. اما في حالة كون فولتية الطور اكبر من القيمة القياسية لفولتية الحمل فسيتم اضافة مسامحة حثية مناسبة الى الشبكة بحيث يتم خفض الفولتية على الحمل الى القيمة القياسية.

عملية السيطرة على الفولتية تتم في زمن اقل من الزمن اللازم لاكمال نصف ذبذبة لفولتية الطور. الخطأ الكلي المصاحب للعملية هو اقل من ٣% .