The Efficiency of the Load in Maximum Power Transfer Position[1]

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Abstract

Electrical and electronic circuit systems are the basic foundations of modern science. These systems are the backbone of the conversion of electrical energy from small size as household appliances to the huge amount of innovation in the technological and industrial appliances. The maximum power transfer theorem is the fundamental principle of electrical circuit analysis, transfer of energy in this circuit with highest power. It further highlights the significance of understanding circuits in education and society, emphasizing the need for students to develop practical and theoretical knowledge. In the simple circuit diagram, the maximum power transfer theorem state that the load of the power is maximum when the load resistance is equal to the internal resistance of the circuit. The efficiency of the load is fifty percent in the circuit at which the power is maximum.

Key words: Maximum power, Load Resistance, Efficiency, Electrical Circuits

Introduction

Electrical circuits are the design which conveying energy from one place to another. As the charged particles move within a circuit, electrical potential energy is transformed from an AC or DC source to any electrical device. This type of energy is either stored in a certain device or it is converted to another form in different energy such as heat energy, sound energy light energy etc. Electrical circuits are useful because they allow energy to be transported without any moving parts. In a closed circuit, only the charged particles are moving in the closed loop. Electrical circuit diagrams are very important to understand the basic knowledge about the electrical system. It is started from the basic level and is continue to the higher courses. The electric circuits will

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examine and analyse by doing some practical applications of the circuits (Svoboda & Dorf, 2013; Lal and Subrahmanyam, 1980; Verma, 1969; Subrahmanyam & Lal, 1966). For this analysis, the basic properties of electrical currents in the circuits must be understood. We have to study the properties of source, applicable parts of the circuit, the transfer of energy in the circuit etc. So many students are unknown about the electrical circuit, which may be applicable in our daily life and in society (Verma, 1969). According to Irwin & Nelms (2010), different form of energy is useful which are getting from the simple electrical circuits. There are various conditions in which transfer of the maximum power from electrical circuits.

Electrical circuits are the foundation of modern electrical and electronic systems. They serve as pathways that allow energy to be transferred from a source, such as a battery or a generator, to different devices that use this energy. When charged particles (usually electrons) flow through a circuit, the electrical potential energy provided by the source is either stored in devices like capacitors or transformed into other forms of energy. Depending on the design of the circuit, this energy may appear as heat in a resistor, light in a bulb, motion in a motor, or sound in a speaker (Bird, 2017). One of the greatest advantages of electrical circuits is that they enable the transfer of energy without any mechanical movement of parts. Electrical circuits differ from engines or machines that require gears, pistons, or belts. Circuits operate due the flow of electrons, which makes them efficient, compact, and dependable. Due of these advantages, electrical circuits form the basis of almost every device we use in daily life. Electric circuits are essential components in wide range of devices from household appliances like fans, refrigerators, and televisions to more advanced technologies such as computers, mobile phones, and medical equipment (Paul, 2001: Nelcon & Parker, 1958).

Understanding about how to read and design electrical circuit diagrams is very important as these diagrams act as a visual representation that explains flow of current, connection of components and distribution of energy (Salam & Rahman, 2018). Usually, circuits are the first subjects covered, and as students' progress, they move on to more complex topics like as alternating current (AC) analysis, semiconductor devices, and digital electronics. In advance studies, circuit analysis is done with the help of simulation software, practical experiments and problem-solving exercises. These things help to connect with real world applications (Svoboda & Dorf, 2013; Alexander & Sadiku, 2017). **In** a simple circuit, the maximum power transfer theorem says that the load gets maximum power when the load resistance is same as internal resistance of the circuit. In other words, power transfer is maximum when load resistance and equivalent internal resistance are equivalent. At this time, circuit is fifty percent efficient. This efficiency is calculated by the ratio of output power to input power (Dorf & Svoboda, 2020).

In circuit theory, the fundamental principle is Maximum power Transfer Theorem. This principle explains the condition in which the circuit receives maximum power from the source. To be more familiar with this, students should not just understand the theory but also apply it in practice as it is used in wide range of areas like communication systems, audio devices and power distribution networks (Bernhard & Carstensen, 2002).

Knowledge of when and how a device takes more energy as well as how efficiency is maintained, helps people see the balance between using energy and saving energy. Many people use electrical devices on a daily basis without knowing the mechanism behind them. Activities such as switching on the light bulb or charging phones may appear easy but involves a complicated electric circuit that manages the use of energy, distribution of power, and maintains efficiency (Salam & Rahman, 2018; Hayt et al., 2019). If students learn more about electrical circuits, they can understand how this process takes place. This can help them in becoming capable engineers, technicians or even users of technology who will be able to make wise energy usage decisions. In this paper, we have learned that electrical circuits play a huge role in our lives and are much more than just concepts. They involve various processes and principles such as energy transfer and maximum power that helps us understand how these circuits function. When students learn about circuits, they are not realized that academic knowledge to their practical uses. This study promotes the idea that when theoretical knowledge is combined with experimental verification, meaningful learning is gained along with practical application.

Theory

The potential energy transfer from higher potential ends to lower potential ends of the conductor. As the current flows, the potential difference on the load, the electric potential energy is lost across the load resistance. Let E be the electromotive force (EMF) of the source with internal resistance ‘r’, K be the switch in the electrical circuit, R be the load resistance, and the ammeter (A) and voltmeter (V) measure the current in the circuit and voltage across the load resistance respectively is shown in figure 1.

The current can be defined as the total potential of the source to the total resistance in the circuit, hence the value of the current flows in the circuit is given by $I = \frac{\text{total emf of the source}}{\text{total resistance in the circuit}}$

Then $I = \frac{E}{R+r}$ ______________ (1)

The potential developed across the load resistance R by passing the current I in the circuit is given by Ohm's law. i.e. Voltage (V) = Current (I) X Resistance (R) that is $V = I \cdot R$ _____ (2).

Now the power is the rate of doing work across the load resistance R, by passing the current I in the circuit is given by

$P = I V = I. I R = I^2.R$. Then substituting the value of I from equation (1) then,

$P = (\frac{E}{R+r})^2 R = E^2\frac{R}{(R+r)}\mathbf{2}$ ___________ (3)

Similarly, the efficiency can be defined as the ratio of output power to the input power. The input power is also called generated power or total power in the circuit. That means the efficiency of the power transfer by the load can be defined as the ratio of output power to the total power in the circuit. It is denoted by η. Then $\eta = \frac{\text{Output power}}{\text{total power}}$

$\eta = \frac{I^2\ R}{I^2\ (R+r)} = \frac{R}{R+r}$______________ (4)

The output power should transfer maximum so the first derivative of power with respect to resistance should be zero and the second derivative must be negative.

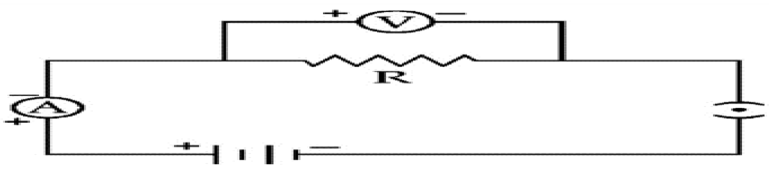
i. e. $P = (\frac{E}{R+r})^2 R = E^2\frac{R}{(R+r)}\mathbf{2}$

$\frac{dP}{dR} = (E)^2[\ (R+r)2 - R\ .\frac{d(R+r)2}{dR}]\ /(R + r)^4$

$\frac{dP}{dR} = \mathbf{E^2\ (r - R)\ /\ (R + r)^3}$______________**(5)**

Figure 1

The electric circuit diagram.



For maximum power, the change in the power with respect to resistance is ($\frac{dP}{dR}$) should be zero. So, $E^2 (r - R) / (R + r)^3$ also should be zero that gives R = r hence, the load resistance or external resistance of the circuit is equal to internal resistance of the source for the maximum power.

To verify the power is maximum, the second derivative should be negative. That means from equation (5), we have to differentiate with respect to resistance at the load resistance{R}is equal to equivalent internal resistance {r}, then the second derivative should be negative.

It proved that the power (P) is maximum, when load resistance (R) is equal to internal resistance (r). At this condition, the efficiency (η) is given by the equation (4) is only half that means fifty percent. Hence, the power transfer is maximum at the position of external and internal resistance equal and the efficiency should be half.

Observation

A load receives maximum power when its resistance equals the internal resistance of the source. Under this condition, efficiency is 50%, meaning half the power is used by the load and half is lost in the source resistance. In the areas of communications, amplifiers, and power generation, or wherever maximum efficiency is important the concept of power theorem is widely utilized. An electrical circuit is a closed path through which electric charges (electrons) flow. It typically consists of source of energy like a battery, generator, or AC power supply. In the closed circuit, the components are connected end-to-end and hence the same current flows through all parts and in open circuit, no current will flow. Similarly, in series circuit the components are connected end-to-end such as old Christmas lights, where if one bulb fails, the whole string goes out in parallel circuit, the components are connected across the same voltage source and hence the current divides between branches. Example of parallel circuit is household wiring. A combination of series and parallel arrangements is called mixed circuit. The electronic boards in computers and televisions are complex in nature. As charged particles move in the electrical circuits the electrical potential energy is transferred in different energy such as in resistors, heaters, or electric stoves as heat energy, in lamps, LEDs, or bulbs as light energy, in speakers and alarms as sound energy, in fans, washing machines, and motors as mechanical energy etc.

The EMF of the source (E) and internal resistance (r) are known values and the external load resistances is variable then the efficiency and power transform in the circuit are calculated by measuring the current in the circuit. Measurements given in the table 1. The power transfer depends on the emf of the source, internal resistance, the external resistances of the circuits etc. as shown in the formula. The graph of power verses load resistance is shown in figure 2 and the efficiency of the load also depends on the load resistances is shown in figure 3. From these two figures combined shown here in figure 4 which shows that the condition for maximum power transform is the load resistance is equal to the internal resistance of the circuit. At this position the efficiency of the load is fifty percent only.

Figure 2

The power transfer versus external resistances of the circuits.

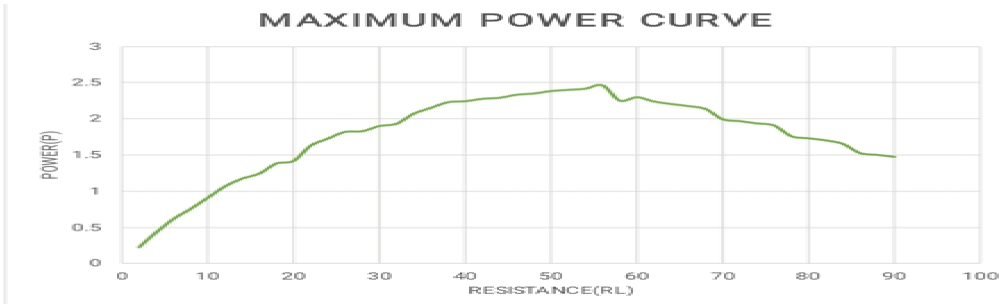


Figure 3

The efficiency of the load versus the load resistances of the circuit.

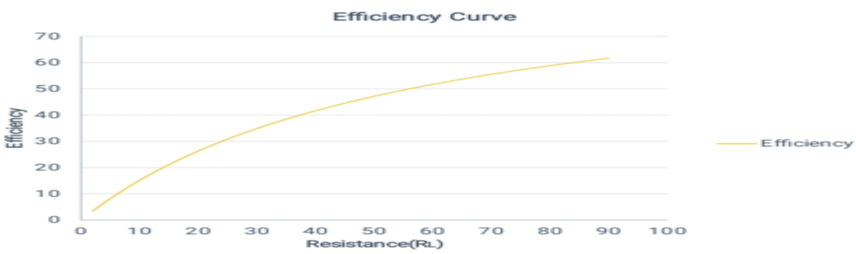


Table 1

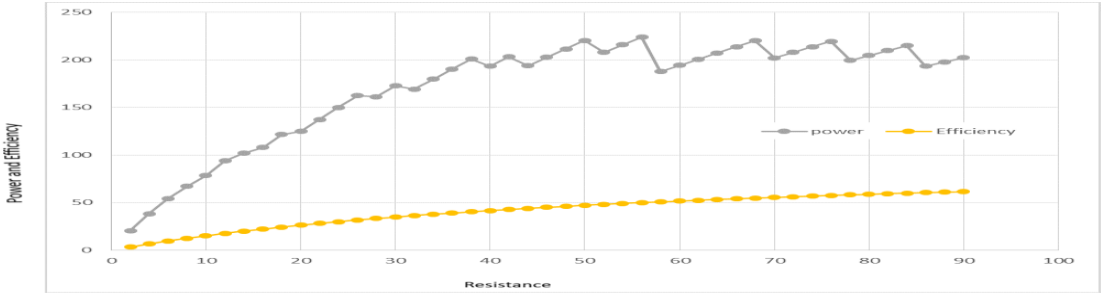
The data of power and efficiency are observed in the laboratory.

S.N.	RL	Current	Voltage	Power	Efficiency
1	2	3.2	6.4	20.48	3.45
2	4	3.1	12.4	38.44	6.67
3	6	3.0	18.0	54.00	9.68

4	8	2.9	23.2	67.28	12.50
5	10	2.8	28.0	78.40	15.15
6	12	2.8	33.6	94.08	17.65
7	14	2.7	37.8	102.06	20.00
8	16	2.6	41.6	108.16	22.22
9	18	2.6	46.8	121.68	24.32
10	20	2.5	50.0	125.00	26.32
11	22	2.5	55.0	137.50	28.21
12	24	2.5	60.0	150.00	30.00
13	26	2.5	65.0	162.50	31.71
14	28	2.4	67.2	161.28	33.33
15	30	2.4	72.0	172.80	34.88
16	32	2.3	73.6	169.28	36.36
17	34	2.3	78.2	179.86	37.78
18	36	2.3	82.8	190.44	39.13
19	38	2.3	87.4	201.02	40.43
20	40	2.2	88.0	193.60	41.67
21	42	2.2	92.4	203.28	42.86
22	44	2.1	92.4	194.04	44.00
23	46	2.1	96.6	202.86	45.10
24	48	2.1	100.8	211.68	46.15
25	50	2.1	105.0	220.50	47.17
26	52	2.0	104.0	208.00	48.15
27	54	2.0	108.0	216.00	49.10
28	56	2.0	112.0	224.00	50.00
29	58	1.8	104.4	187.92	50.88
30	60	1.8	108.0	194.40	51.72
31	62	1.8	111.6	200.88	52.54
32	64	1.8	115.2	207.36	53.33
33	66	1.8	118.8	213.84	54.10
34	68	1.8	122.4	220.32	54.84
35	70	1.7	119.0	202.30	55.56
36	72	1.7	122.4	208.08	56.25
37	74	1.7	125.8	213.86	56.92
38	76	1.7	129.2	219.64	57.58
39	78	1.6	124.8	199.68	58.21
40	80	1.6	128.0	204.80	58.82
41	82	1.6	131.2	209.92	59.42
42	84	1.6	134.4	215.04	60.00
43	86	1.5	129.0	193.50	60.56
44	88	1.5	132.0	198.00	61.11
45	90	1.5	135.0	202.50	61.64

Figure 4

The efficiency of the load given by orange colour and output power of load is given by grey colour are taken along Y-axis and the load resistances of the circuit is taken X-axis.



Electricity is very important in our daily lives. It powers things like lights, phones, hospitals, home appliances and factories. The main part of any electrical system is the electrical circuit which refers to a closed path that lets electricity flow. A circuit carries energy from a source (like a battery) to a device (like a bulb or a motor) that uses it or changes its form. Even though circuits are everywhere, most people don't know much about how they work. In fact, even researchers often use electrical devices without fully understanding how energy moves in it, how efficient the device is, or how much power it uses (Alexander & Sadiku, 2017). The theoretical calculations and experimental calculations are consistent and gives the same idea by which the students can learn meaningful practical applications.

Importance of circuits

Circuit diagrams use symbols used to represent real-life systems, making them clear and standardized. Understanding these diagrams is very important for designing, analyzing and troubleshooting electrical systems. According to Dorf and Svoboda (2020), knowing about circuit diagram is a fundamental part of electrical engineering, beginning with simple resistive circuits in secondary education and progressing to more advanced AC/DC networks and semiconductor circuits in higher studies. Despite the widespread use of such devices in everyday life, people are unaware of the circuits functioning within them which shows importance of these circuits. This theorem is applied in various systems like communication systems where maximum signal power is important, in audio systems to make sure speakers receive optimal power, and power networks for maintaining efficiency and effective energy transfer.

Household electrical devices like lightning, refrigerators, fans and televisions work well only if their circuits are functioning properly. In industries, advanced electrical circuit configurations play important role in running motors, automated systems, and robotics. In healthcare sector, important medical equipment like X-ray machines, ECG monitors, and ventilators function also rely on electrical circuits to operate. Similarly, in communication technologies, circuits form backbone of data transmission and signal processing, from mobile phones to satellite (Sedra & Smith, 2015; Von Meier, 2024).

Learning about circuit is very important for students at every stage of learning. Circuits are like a connection or a bridge between theoretical physics to real life application which makes abstract concept more meaningful. When students learn about circuit analysis, they develop problem solving abilities and logical thinking. This improves their critical thinking skills. It also helps them to become more aware about everyday use of energy in various devices and how efficiently it can be improved. Also, knowledge about circuit encourage students come up with innovative ideas and inventions in various fields like renewable energy and modern electronics. Though we use various electronics like phone and computer all time, a lot of students are unaware of their operation. Combining practical experiments and real-life application helps students better understand the topic and make them become more interested in topic leading to deeper and more lasting understanding.

Conclusion

Electrical circuits play an important role in modern life. Circuits power everything, from a simple household device to advanced technologies used in medical and communication technologies. This makes everyday life possible and more efficient. When students learn about circuits, they not just learn academic knowledge, they also develop practical skills to analyze, design and optimize electric systems around them. This study promotes the idea that when theoretical knowledge is combined with experimental verification, meaningful learning is gained along with practical application.

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