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Energy Harvesting System using Current Transformer

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Abstract - *In power system, power lines are monitored for current level by large number of electronic devices. These devices require power for its operation for which auxiliary power source is required. Current transformer can be used as energy harvester to extract power from the power lines based on electromagnetic induction. This energy can be used to meet the power requirement of the devices. Current transformer obtains energy directly from the power lines. Switching regulator changes rectified voltage signal into stable DC voltage signal to supply regulated DC power. This paper introduces the design of a regulated power supply based on electromagnetic energy harvesting using a current transformer. Saturation problem of the current transformer when primary current increases beyond the limit is eliminated using a switching technique. In this paper, power supply by one current transformer is designed.*

Key Words: Current transformer, Energy harvesting, Power supply, Saturation, Power devices, Regulated DC

1. INTRODUCTION

Current flowing in the power lines generates magnetic field. This magnetic field can be used as a source of energy caused by electromagnetic induction principle. Same principle is used in a current transformer(CT). Current transformers can be efficiently used for energy harvesting from line currents. Current transformer extracts energy from power lines based on the electromagnetic theory. Current transformer samples the current in a line and reduce it to a safe and measureable level. For energy harvesting, the CT must be prevented from going into saturation for the entire input current range. CT will provide alternating power, which has to be rectified and regulating prior feeding to the load.

1.1 Current Transformer

CT consists of two or more coils of wire wrapped around a common ferromagnetic core. These coils are connected by the common magnetic flux present within the core. One of the transformer windings is connected to a source power, and the second transformer winding supplies power to loads. The transformer winding connected to the source is the primary winding, and the winding connected to the load is secondary winding. Core supports both the windings and as well as acts a medium for magnetic coupling between both the windings.

Current transformer is a constant power device, that is the primary power (Pp) equals the secondary power (Ps). Ideal power equation would be:

$$Pp = Ip\ Vp \quad (1)$$

$$Ps = Is\ Vs \quad (2)$$

$$Ip\ Vp = Is\ Vs \quad (3)$$

Where, Vp is primary voltage and Vs is secondary voltage.

Primary current (Ip) and secondary current (Is) are also related as:

$$Ip\ Np = Is\ Ns \quad (4)$$

Hence,

$$Vs/Vp = Ip/Is = Ns/Np \quad (5)$$

Above equation is considered only when the CT works in the linear region. Practically CT goes in the saturation state. The performance of the current transformer is limited by the amount of the magnetic flux in the core. The secondary current is substantially proportional to the primary current under normal operating condition. Core tends to saturate after a certain level of magnetic flux is attained in the core. Saturation causes distortion in the secondary voltage and heating issues in the core. Saturation level in the core depends on core area, turns ratio, primary current, secondary burden etc. CT saturation is the state where a CT is no longer able to produce an output in proportional to its primary current or as per its ratio. For energy harvesting application, it is desired that the current transformer should not go in the saturation state.

1.2 Current Transformer Analysis

According to the law of electromagnetic induction, the secondary side voltage (Vs) of CT with unsaturated core is given as:

$$Vs = \sqrt{2}\ \pi\ f\ Ns\ \phi m \quad (6)$$

Where, f operating frequency is and ϕm is effective magnetic flux through the core.

$$\phi m = Bm\ A \quad (7)$$

where, Bm is maximum saturation flux density and A is core cross-sectional area.

In linear region of core operation,

$$B = \mu\ H \quad (8)$$

Where, μ is magnetic permeability of the material and H is magnetic field intensity.

According to Ampere circuit law,

$$Hm\ L = \sqrt{2}\ Np\ I\mu \quad (9)$$

Where, Hm is maximum magnetic field intensity, L is average magnetic path length and Iμ is magnetizing current.

Substituting (9), (8) and (7) in (6) we get,

$$Vs = \sqrt{2}\ \pi\ f\ Ns\ Bm\ A = \sqrt{2}\ \pi\ f\ Ns\ \mu\ Hm \quad (10)$$

$$Vs = \sqrt{2}\ \pi\ f\ Ns\ \mu\ \sqrt{2}\ Np\ I\mu\ A\ /\ L$$

$$Vs = (2\ \pi\ f\ \mu\ Np\ Ns\ I\mu\ A)\ /\ L \quad (11)$$

From this equation it can be seen that secondary side output voltage of CT is related to primary side excitation current and has not dependent on secondary side current. Equation shows that, if core parameters and number of turns in the windings are fixed, then the secondary side output voltage is only related to the primary side excitation current. The higher the excitation current, higher will be the voltage.

According to the equilibrium equation of magneto-motive force of the transformer (ignoring core losses),

$$Ip\ Np + Is\ Ns = I\mu\ Np \quad (12)$$

Substituting (12) in (11),

$$Vs = (2\ \pi\ f\ \mu\ Ns\ A)\ (Ip\ Np + Is\ Ns)\ /\ L \quad (13)$$

Above equation can be simplified to obtain primary current as

$$Ip = [(Vs\ L)\ /\ (2\ \pi\ f\ \mu\ Np\ Ns)] - [(Ns\ Is)\ /\ Np] \quad (14)$$

Where, Hm is maximum magnetic field intensity, L is average magnetic path length and Iμ is magnetizing current.

1.3 Magnetization Curve

From the magnetization curve, CT operation can be categorized into two regions, linear region and saturation region.

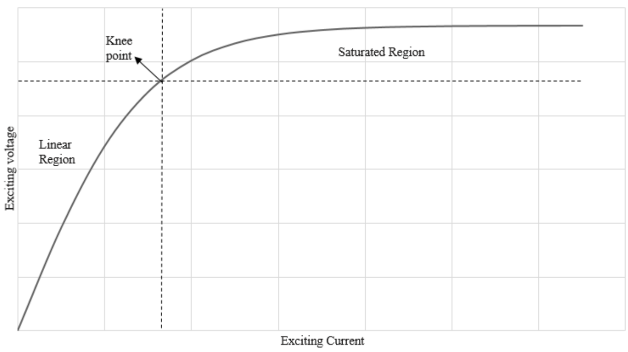

Fig -1: Magnetization or excitation curve

In linear region, magnetic flux density is approximately proportional to field intensity, i.e. it is increasing linearly. But in the saturation region, when field intensity increases, increase in flux density slows down and eventually it remains constant.

2. BLOCK DIAGRAM

Current transformer based power supply circuit block diagram is shown in the figure. Current transformer generates AC voltage and current. This AC voltage is rectified by the rectifier module and then regulated to a stable DC voltage. The circuit consists of a protection switch whose function is to eliminate the effects of current transformer saturation. Rectifier converts the AC voltage output into unregulated DC voltage and filter reduces the output voltage ripple of the rectifier. Current transformer produces output secondary voltage which is proportional to input primary current. Regulator is used to obtain regulated and constant output voltage for all the primary current variation.

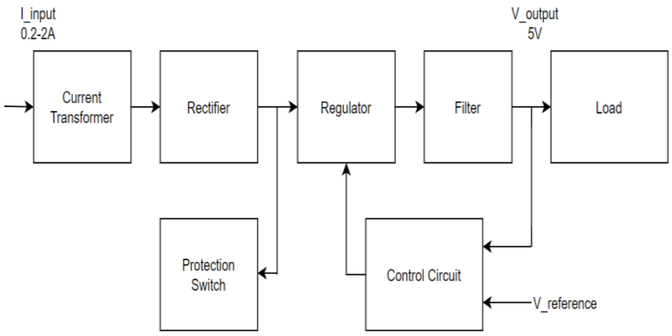

Fig -2: Block diagram of the system

In the block diagram the input to the CT is fed from one phase of the power line that varies from 0.2A to 2A. During faults the line current may rise above 2A. Rectifier and filter converts the AC output of CT into DC voltage. The voltage required to drive the load is 5V. With the help of control circuit and regulator, the output voltage is maintained constant at 5V even when the input primary current of the CT is increased or decreased. It is desired that the current transformer should not go in the saturation state for the entire input current range.

3. DESIGN EQUATIONS

Current transformer:

$$Ip = (Np\ /\ Ns)\ Is \quad (15)$$

$$Is = Vs\ /\ Rs \quad (16)$$

Where, Rs is secondary resistance.

Rectifier:

$$Idc = \sqrt{2}\ (2/\pi)\ Iac \quad (17)$$

Where, Idc is rectifier output current and Iac is rectifier input current.

$$Idc = 0.9\ (Np/Ns)\ Ip \quad (18)$$

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Load:

Vo = Io Ro (19)

Where, Vo is load voltage, Io is load current and Ro is dc load.

4. OBSERVATIONS

Table -1: When Ro = 1000 ohms

Primary current Ip (A)	Secondary current Is (A)	Ro = 1000 ohms	
		Vo (V)	Io (A)
0.1	0.023	5	0.005
0.2	0.046	5	0.005
0.3	0.069	5	0.005
0.4	0.092	5	0.005
0.5	0.115	5	0.005
0.6	0.138	5	0.005
0.7	0.161	5	0.005
0.8	0.184	5	0.005
0.9	0.207	5	0.005
1.0	0.230	5	0.005
1.2	0.276	5	0.005
1.5	0.346	5	0.005
1.8	0.415	5	0.005
2.0	0.461	5	0.005

Table -2: When Ro = 2000 ohms

Primary current Ip (A)	Secondary current Is (A)	Ro = 2000 ohms	
		Vo (V)	Io (A)
0.1	0.023	5	0.0025
0.2	0.046	5	0.0025
0.3	0.069	5	0.0025
0.4	0.092	5	0.0025
0.5	0.115	5	0.0025
0.6	0.138	5	0.0025
0.7	0.161	5	0.0025
0.8	0.184	5	0.0025
0.9	0.207	5	0.0025
1.0	0.230	5	0.0025
1.2	0.276	5	0.0025
1.5	0.346	5	0.0025
1.8	0.415	5	0.0025
2.0	0.461	5	0.0025

5. RESULTS

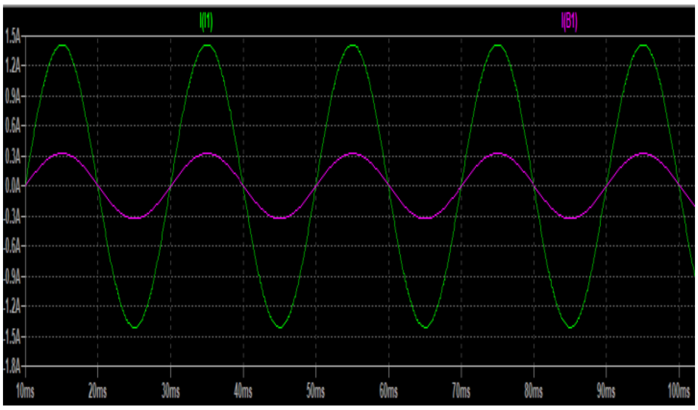

Fig -3: Primary and secondary current

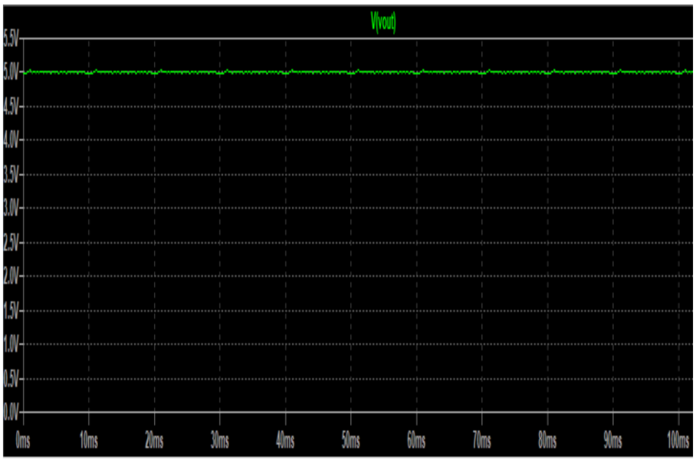

Fig -4: Output voltage at Ro = 1000 ohms

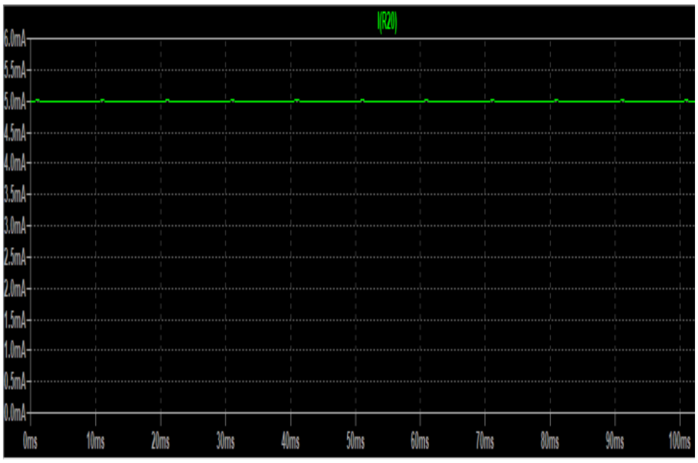

Fig -5: Output current at Ro = 1000 ohms

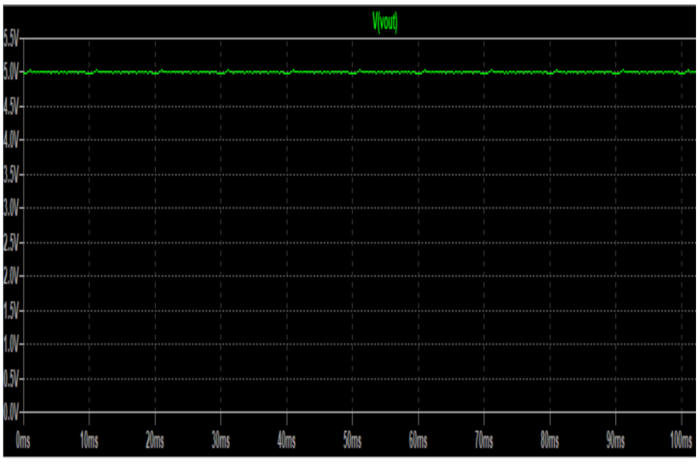

Fig -6: Output voltage at Ro = 2000 ohms

Fig -7: Output current at Ro = 2000 ohms

6. CONCLUSIONS

This paper presents energy harvesting scheme based on current transformer. Power line current is fed as the input to the current transformer. It can be seen from the observation table and the output waveforms that the current transformer is able to fed the load with constant voltage of 5V for the entire range of the input current from 0.2A to 2A. Regulator efficiently converts the CT secondary voltage into a constant fixed voltage required by the load.

REFERENCES

[1] Ahola, J., et al. "Design considerations for current transformer based energy harvesting for electronics attached to electric motor." 2008 International Symposium on Power Electronics, Electrical Drives, Automation and Motion. IEEE, 2008

[2] Kai Chen, Zi-jian Zhao, Yu-ning Zhang, Yang-chun Cheng, Yuan Dai, "Design of Power Supply for On-line Monitoring System of Transmission Lines," Scientific Research, Energy and Power Engineering, July 2013, 5, 570-574

[3] Hargrave, Ariana, Michael J. Thompson, and Brad Heilman. "Beyond the knee point: A practical guide to CT saturation." 2018 71st Annual Conference for Protectuve Relay Engineers (CPRE). IEEE,2018.

[4] R Colonel Wm. T. Mclyman, Transformer and inductor design handbook third edition, revised and expanded.

[5] Manivasagam Rajendran, and Vigneshwaran Perumal, "Saturation analysis on current transformer," International Journal of Pure and Applied Mathematics, Volume 118 No. 18 2018, 2169-2176

[6] Powell, Louie J. "Current transformer burden and saturation." IEEE Transactions on Industry Applications 3 (1979):294-303

[7] Wang, Rui, et al. "Design considerations of maximum energy harvesting and voltage control from high voltage power cables." 2014 International Power Electronics and Application Conference and Exposition. IEEE, 2014.