An Adaptive Impedance Matching Technique for Narrowband Power line Communication in Residential Smart Grids

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Abstract*— Power line communication is a cost-effective, facile and reliable tool for the current electrical distribution grid and will play a significant role towards realizing smart grids in future. Low voltage electrical networks provide a harsh environment for data communication. Significant attenuation, noise, interferences, multipath reflections and overall unpredictable and time varying access impedance are some of the major problems faced by power line communication in its current state. The demand for smart greenhouses is rapidly increasing to meet the energy demand in future. So the need of an effective communication link between main grid and the residential grid is inevitable. This paper aims at removing one of the big hindrances in achieving power line communication, which is impedance mismatchbetween the communication system side and load side.Although there are many impedance matchingtechniques, but one of the biggest problems they face is their static nature i.e. they are designed to match a particular load. Due to time varying nature of residential loads a static impedance matching circuit fail to achieve its purpose. So here we discuss about an adaptive impedance matching circuit which automatically matches to the varying impedance and therefore helps in providing better perceptive of power line communication in real applications.

Keywords—Impedance matching,Coupling transformer, Narrowband power line communication (N-PLC)

I. Introduction

Narrowband Power line communication or N-PLC refers to transferring data over power line in a restricted frequency band of 3 KHz to 148.5 KHz. This band of frequency has been widely applied over the electricity distribution grid for achieving home automation, automatic meter reading and many other applications. Through N-PLC all electrical devices plugged into the main grid in a particular area, can have a common communication link by utilizing the same power line, rather than using external wires and sensors. The performance of any PLC system generally depends on time, location and power network wiring topology [1]. Power line provides a harsh environment for data transfer including multiple reflections, interferences, noise and over all time varying access impedance. In such scenario impedance matching between communication system and load plays a vital role in improving range of data transmission and also maintaining appropriate signal strength. The power level of signal should also be within the limit so that Electromagnetic Interference (EMI) through emissions will not exceed the levels allowed by regulations else the energy burst will disturb the other wireless users in adjacent frequency bands [3]. If the transceivers and the channel impedance can be matched, not only the signal power delivered from one node to another can be maximized, but also signal reflections can be minimized. To be more specific, if the reactance in the channel is fully matched via a coupler, the power efficiency can be increased dramatically. Therefore this paper aims at proving an adaptive impedance matching circuit which would automatically remove the inherit problem of varying access impedance of residential loadsand help in achieving effective power line communication.

II. Ease of Use

In this paper we have discussed the basics of impedance matching in first part. The second part describes impedance matching through tap changing coupler transformer and its performance characteristics. The third part consists of a feedback circuit which would help in giving an idea about the timely change in access impedance and the fourth part combines the second and third part to provide an adaptive impedance matching circuit which is followed by concluding remarks.

III. Brief Overview of Impedance Matching

Impedance matching is the practice of designing the input impedance of an electrical load (or the output impedance of its corresponding signal source) to maximize the power transfer or minimize reflections from the load. In this section we briefly discuss what are the various standard impedance matching designs and schemes, and then a detail simulation of each technique with their performance analysis is provided in the subsequent sections.

A. Basic Impedance Matching

The maximum power-transfer theorem says that to transfer the maximum amount of power from a source to a load, the load impedance should match the source impedance. In the basic circuit, a source may be dc or ac, and its internal resistance (R_i) or generator output impedance (Z_g) drives a load resistance(R_L) or impedance (Z_L) as shown in fig. 1. However in real time applications load and source impedance don't match so we need to provide an impedance matching circuit to achieve maximum power transfer from source as shown in fig. 1.

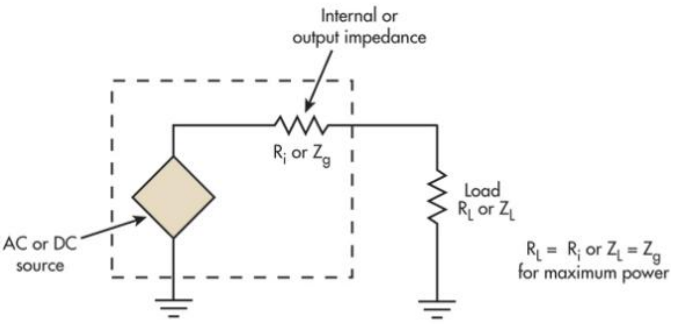

Fig. 1. Basic electrical circuit.

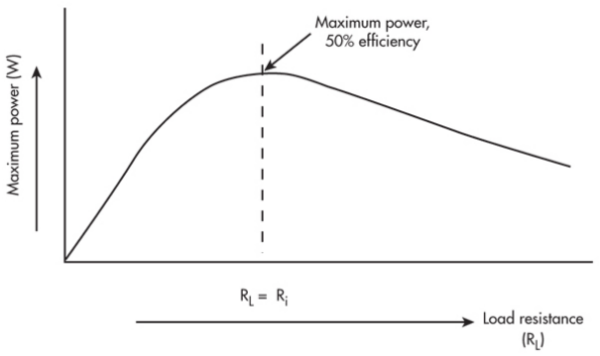

Fig. 2. Plot of source power vs. load resistance.

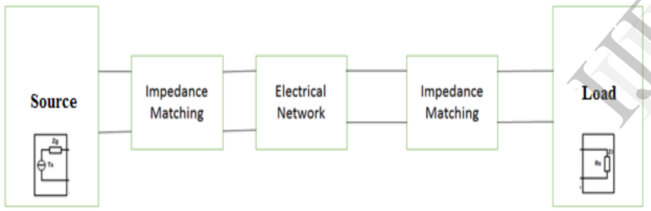

Fig. 3. Basic layout of impedance matching.

B. Impedance Matching in Power Line Communication

One of the major thrust areas in improving power line communication is impedance matching. Fig. 4 shows the basic layout of power line communication and fig shows the change which needs to be made to improve the system. There are various methods to match transceiver and access impedance either by using an external circuit to bring impedance change or make changes in existing circuit to bring change.

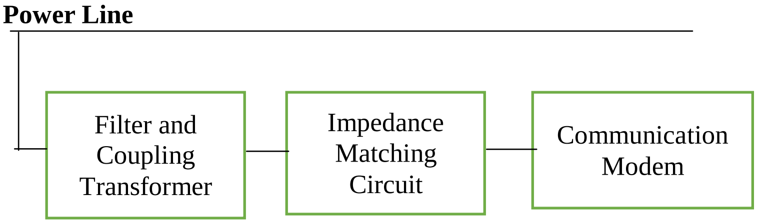

Fig. 4. Basic scheme of power line communication with impedance matching circuit.

1) ***Impedance Matching using tap changing coupler transformer***

The coupling circuit can help in impedance matching by using a tap changing transformer instead of using a fixed 1:1 transformer [2, 7, 8]. This method provides a cost effective way of achieving impedance matching without using any external components. Although the tap of the coupling transformer need to be controlled effectively by a micro controller using a feedback from the power line side.

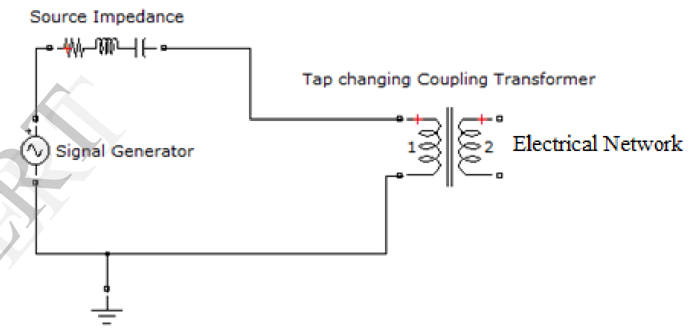

Fig. 4. Variable Coupling transformer along with transmitter circuit.

Matlab and Simulink are used to create a similar environment for power line communication as it would see in real life situation. The simulation scheme consists of a 230volt low voltage AC transmission line between the distribution transformer and residential units. The distance is assumed as 1Km (typically few hundred meters). The transmitter circuit is a 130 KHz signal generator having a source impedance of 50ohms which is connected to a 230volt AC line through a coupling capacitor. The receiver circuit similar to transmitter is placed near one of the house loads.

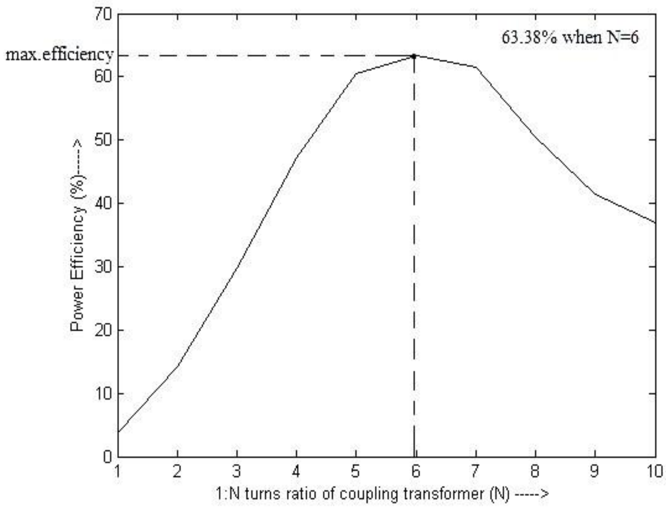

Fig. 5. Plot between efficiency and turns ratio of coupling transformer without any impedance matching transformer (refer fig. 4 for circuit)

In the simulation by manually changing the coupler transformer's turns ratio we were able to increase the efficiency upto certain limit but this changing of taps can be automated if we can collect some information about the access impedance such that the transformer always operate at a truns ratio which provides maximum efficiency for signal.

IV. MEASUREMENT OF REFLECTED POWER DUE TO IMPEDANCE MISMATCH

When a transmission line is terminated in a matched load - in other words, a load equal to the characteristic impedance of the line - the RF voltage and current are constant along the line. Losses in a real life line will mean that the voltage and current will slightly but steadilydecrease as we travel away from the transmitter. When the line is terminated in a mismatched load, standing waves will appear - the voltage and current vary up and down, going through a complete cycle in each electrical wavelength along the line.We can visualize the standing wave as the result of two separate waves travelling in opposite directions. Concentrating for the moment on the voltages, we can visualize a forward travelling voltage wave E_F from the transmitter, and a reverse-travelling voltage wave E_R reflected from the mismatched load, refer fig. 6. A reactive load determines the initial phase relationship between E_F and E_R at the load itself, but it is the addition and cancellation between E_F and E_R in progressively-changing phase that creates the standing wave along the line.

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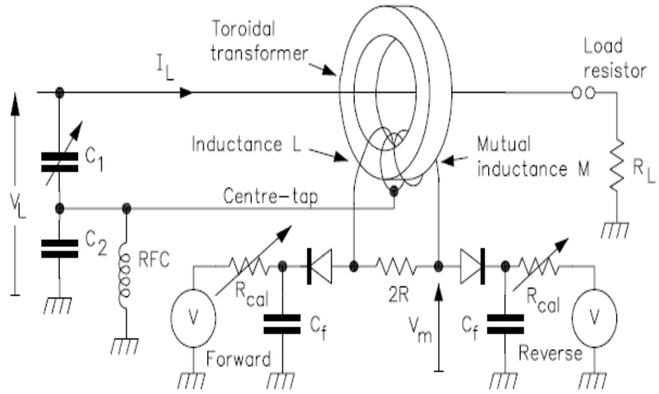

Fig. 6. Basis design of the circuit which can measure the E_f and E_r.

Standing Wave Ratio or $$SWR = \frac{1+\frac{E_r}{E_f}}{1-\frac{E_r}{E_f}} \quad (1)$$

Standing wave ratio (SWR) is the ratio of the amplitude of a partial standing wave at an antinode (maximum) to the amplitude at an adjacent node (minimum), in an electrical transmission.In (1),$E_r$proportional to Voltage reverse and E_f proportional to Voltage forward. Using Matlab and Simulink, simulation of Fig. 6 was done and the result is shown below in fig. 7. The SWR tends towards one when source impedance matches load impedance. So this circuit can prove to be an effective feedback tool for the variable tap coupler transformer which was discussed above. We can also replace the toroidal transformer by a bidirectional current sensor as shown in fig. 8.

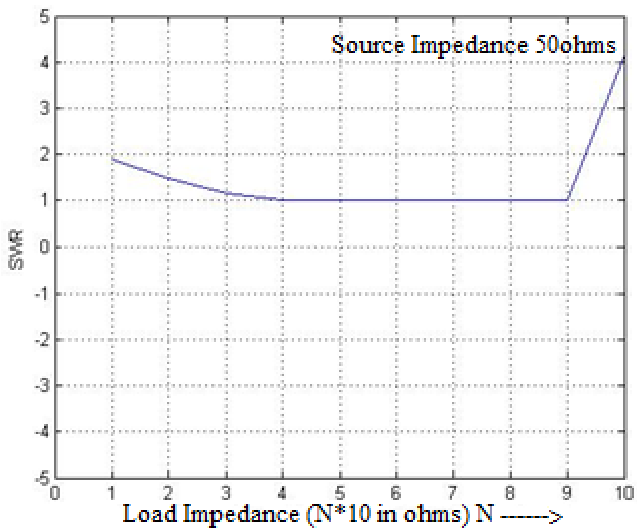

Fig. 7. Plot of Load Impedance vs. SWR.

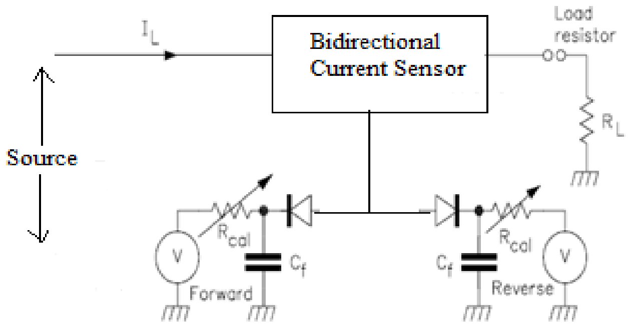

Fig. 8. A simpler circuit for measuring reflected power.

V. An Adaptive Impedance Matching Technique

The prosed reflected power measuring circuit and the tap changing coupler transformer based impedance matching circuit can be used together to form an adaptive impedance matching system without even actually measuring the access impedance. Fig. 10 shows how the adaptive impedance matching technique tries to maintain maximum efficiency at various load.

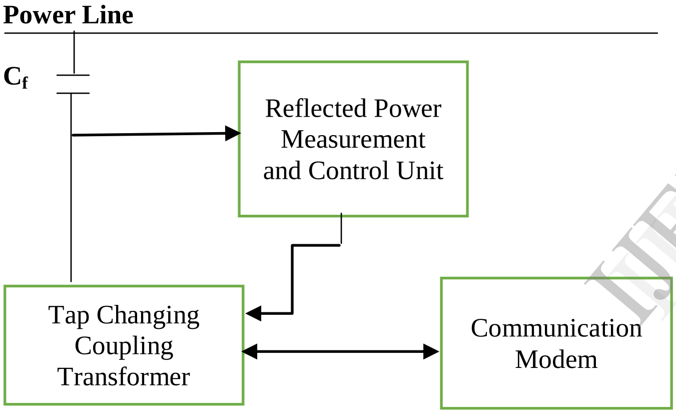

Fig. 9. Basis Configuration of Adaptive Impedance Matching Technique

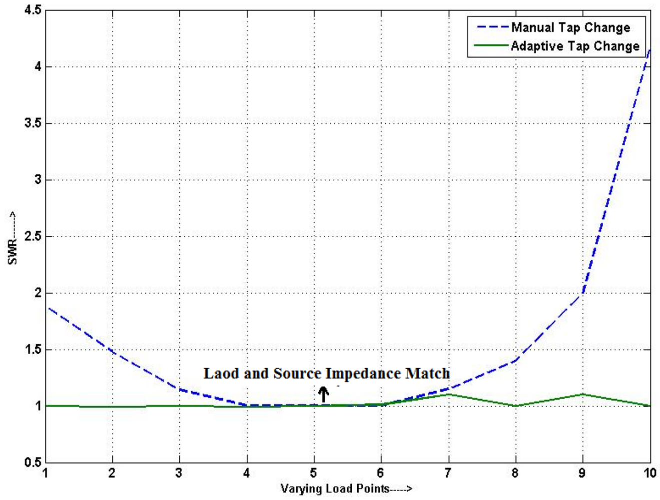

Fig. 10. Plot of varying SWR with changing load for both manual and adaptive tap control

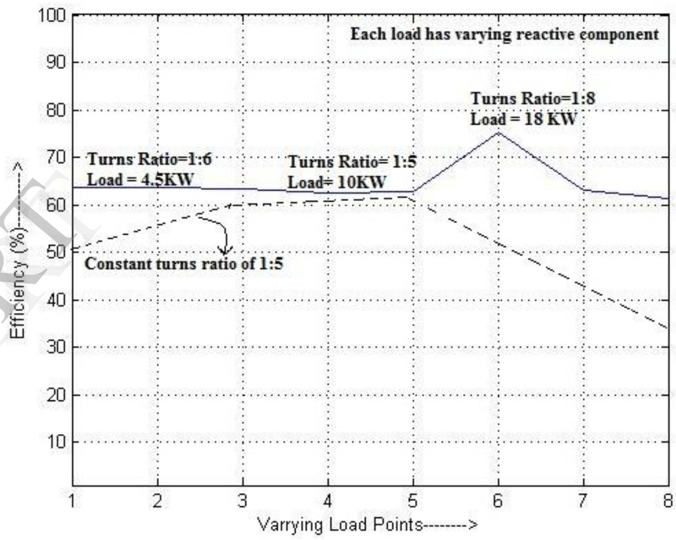

Fig. 11. Plot of varying load vs. efficiency showing both adaptive and manual tap changing technique.

VI. Conclusion

Considering the above results we can conclude that an adaptive variable coupling transformer for the transceiver circuit would prove really effective for impedance matching and maximum power transfer. The future work would aim at hardware implementation of the proposed system and real time testing.

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