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An Evaluation of Smart Electricity Meters in Noisy Electromagnetic Environments

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Abstract— **Due to increasing of electronics and digital circuits in all sides of daily life, the electromagnetic pollution is increasing daily. The performance of electronic and electrical equipment is much influenced by this electromagnetic pollution. Now day most of energy meters are still electromechanical. But due to the advantages of smart meters, the conventional meters are being replaced by them. As part of a smart grid, smart meters will be everywhere, and not always in the most ideal operating conditions (inside transformer rooms or near to mobile phone base stations). So these EM noises might affect the performance of meters. EMI/EMC evaluation has thus become necessary to ensure that these meters work satisfactorily in the present day environment. Investigations of the performance of smart meter under radiated electromagnetic disturbances will be studied in this paper. Their performance characteristics with respect to the ones measured in absence of electromagnetic field will be compared.**

Index Terms— **Smart meter, electromagnetic compatibility, immunity testing, field uniformity, GTEM**

I. INTRODUCTION

The need for energy is increasing due to the growth of population census and industrial development. Energy consumers have to be more aware of their energy consumption, so the energy efficiency can be improved. In recent years, energy companies have announced about new electric energy meters which are known as smart meters. Smart meter is a digital energy meter that measures the consumption of electrical energy and provides other additional information as compared to the traditional meter. All smart meters have a communication module to able to send and receive electricity data via telecommunication network to a central system [1].

Electromagnetic disturbances always represent an explicit threat to all electrical and electronic devices. The achievement of adequate immunity for these devices is a basic Provision to ensure electromagnetic compatibility (EMC) in these circumstances. EMC is the capability of electrical and electronic systems, equipment, and devices to operate in their intended electromagnetic environment within a defined margin of safety, and at design levels of performance without suffering or causing unacceptable degradation as a result of electromagnetic interference. Immunity testing analysis is carried out by subjecting the smart meter system to threats considered by IEC 62052-11 [2] and following the test procedures prescribed in IEC 61000-4-3 [3]. EMC laboratories introduced several test environments to test smart meter systems for radiated immunity. Instead of using an open area test site or a semi-anechoic chamber, a gigahertz transverse electromagnetic (GTEM) cell is used as a simple piece of measurement equipment to evaluate the response of small pieces of equipment under test exposed to electromagnetic field radiation under conditions approximating free space [4].

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Measuring electronic instruments should be tested under conditions as similar to the actual conditions of their operation as possible. When the communication modules are installed in the smart meter devices, these modules should be included in the EMC testing and evaluation. However, at present, the kilowatt-hour meter standard does not consider testing of meters incorporating with such communication modules. Investigations of the performance of smart meter under radiated electromagnetic disturbances will be studied in this paper. Their performance characteristics with respect to the ones measured in absence of electromagnetic field will be compared.

II. SMART METER

Whether you believe in manmade climate change or not, it is a fact that, our energy supplies are depleted faster than they can be replaced. The majority of fossils fuel supplies are likely to run out this century and until an equivalent energy production can be achieved from renewable sources, our daily energy consumption are needed to be monitored and controlled. This can be done by using smart meters. They are widely used by international energy companies in household and business locations for the metering of energy consumption. Smart meters can act as the gateway to intelligent devices and appliances in the home, and provide the foundation of new tariff programs.

The energy meter system use one-way communication to collect the data represents automated meter reading (AMR) system. While the system that use two-way communications with the ability to control and monitor the meters represent advanced metering infrastructure (AMI) system. The combination of automatic reading and two-way communications are the reason why the meter is called smart [6]. Smart metering added remote control abilities to the electricity grid. For instance, electricity grid can shut down several customers simultaneously on short notice – in order to balance the grid in case of an incident [7].

Smart meter design contains three main internal areas, the power system, microcontroller, and communication interface.

The main and auxiliary sections of a smart meter design are shown below in Fig.1. The main communication methods available for use in smart meter systems are radio frequency (RF) mesh networking, power line communication networking (PLC), and GPRS networking. The PLC and GPRS networking methods make use existing resources such as power lines and mobile phone networks of public wireless carriers. So they can minimize the cost of constructing a new RF mesh network [8]. Designing a smart meter requires to be properly shielded from external sources for not degrade the smart meter's performance and to increase its immunity against external disturbances.

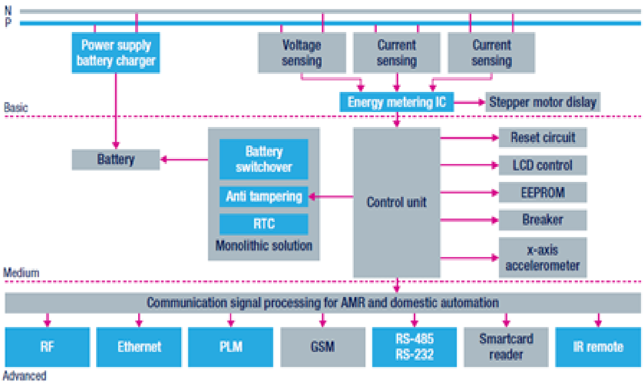

Fig. 1: Smart Meter Block Diagram

III. IMMUNITY TESTS CONCERNING SMAER METER SYSTEMS

The main issue of EMC is to make sure that a device or system is able to function without failure in its intended electromagnetic environment. Smart meter is very sensitive measurement circuits that must be protected from distortion because of external EMI sources. Smart meter is a measuring instrument has a certain accuracy under normal operations, but it may lose accuracy during specified electric field are applied. Electrical standards require a meter to be fully functional and that the application of High-frequency noise must not produce any change in the KWh reading in the register. Radiated electromagnetic fields may be directly coupled onto the printed circuit wiring when the assembly is not shielded [9].

Radiated immunity test for energy meter is part of type compulsory tests against disturbing EMC effects and it is prescribed by basic standard IEC 61000-4-3 [10]. Radiated immunity test includes two steps. In the first step, preparation of uniform field area (UFA) which is the homogenous area of EM field inside the testing chamber. The required levels of power from signal generator for certain frequency points can be obtained by calibrating procedures. In the second step the immunity test is performed using the signal levels collected during the calibration procedures [5].

In order to test for radiated immunity, several test environments and procedures are applied in EMC laboratories. There are different immunity test environments were defined in individual standards, i.e. IEC 61000-4-3 [3] for anechoic chambers, IEC 61000-4-20 [11] for TEM waveguides, IEC 61000-4-21 [12] for reverberation chambers and the future IEC 61000-4-22 [13] for fully anechoic rooms. Instead of using an open area test site or a semi-anechoic chamber, a gigahertz transverse electromagnetic cell (GTEM) is used as a simple piece of measurement equipment to evaluate the response of small pieces of equipment under test exposed to electromagnetic field radiation under conditions approximating free space. It is possible to use a GTEM cell to measure emissions and perform immunity testing for frequencies from DC to several GHz [4]. GTEM cell used for tests and the main equipment involved in the realization of tests are presented in table 1.

Table 1: Instruments used for the immunity tests

Instrument	**Manufacturer**	**Model**	**Frequency Range**
RF Signal generator	Rohde & Schwarz	SMC100A	9 KHz -3.2 GHz
RF Power Amplifier	Frankonia	FLHG-150C	20 MHz – 3 GHz
RF Relay Switching Unit	Frankonia	RSU - 1203	DC – 40 GHz
Power Sensor	ETS - Lindgren	HI - 6005	9 KHz -6 GHz
Portable Reference Standard	ZERA	MT300	
GTEM Cell	Frankonia	1000	10 KHz -3 GHz
GSM Cell Phone Repeater	Any Tone	AT - 400	Up 890 – 915 MHz Down 935 – 960 MHz

A. Field Calibration inside GTEM Cell

According to IEC 61000-4-20 [11], a GTEM cell used for immunity measurements has to be tested for field uniformity and cross-polar coupling. Depending on the test volume, the field strength has to be measured at a certain number of calibration points in a vertical plane. The field strength has to be within 6 dB of the nominal value at 75 % of these measured points. Cross-polar components have to be at least 6 dB lower than the resultant field strength calculated from the three field components. Generally, the calibration is performed with a field sensor while the field strength is generated using a signal generator and amplifier monitored by a power meter [11]. As shown in Fig. 2, GTEM cells provide excellent field uniformity.

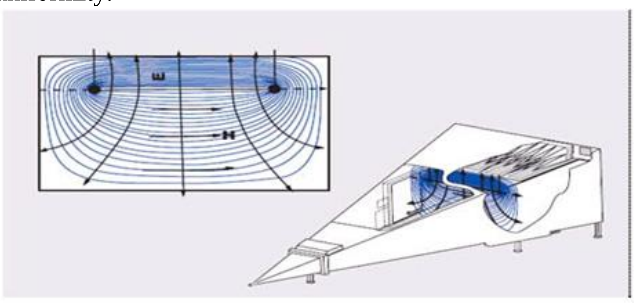

Fig. 2: EM Field Distribution in the GTEM Cell

Fig. 3 shows different grid sizes for the uniform area as required by IEC 61000-4-20 [11]. For a smaller 0.5 m by 0.5

m area an extra central point would have to be added to a 4-point grid. For the research presented here, a 9-point 1 m by 1 m grid was used. And according to IEC 61000-4-20, 7 of 9 points have to be within 6 dB of the nominal field strength value. Fig. 4 depicts the graphical representation of the power required for tests according to the present standards for various types of GTEM. Each type of GTEM may generate a certain power as mentioned on the right vertical axis, therefore enabling the performing of tests according to norms [15].

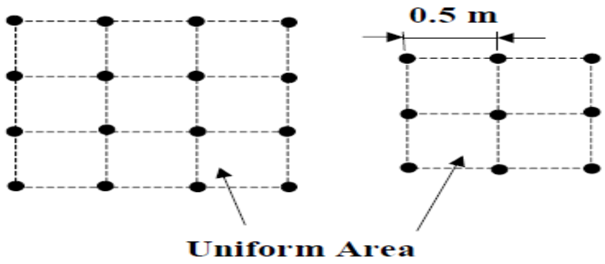

Fig. 3: The 16-point and the 9-point grid for field uniformity

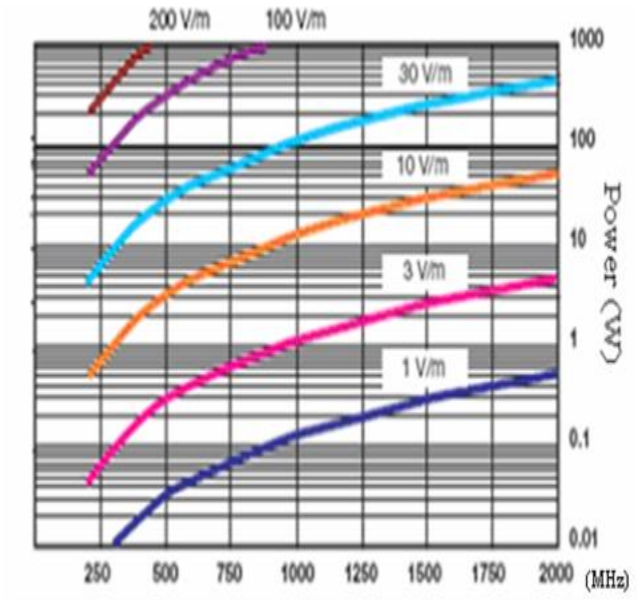

Fig. 4: Power Required for a Given Field Strength for IEC 61000-4-20

The field strength of the uniform field was established and measured via a calibrated field sensor at each particular frequency and at each of the 9 points one after the other using the step size which was not exceed 1 % of the preceding frequency value by adjusting the forward power accordingly. The forward power necessary to establish the field strength at the starting position was measured in accordance with Fig. 3. The same forward power was applied for all 9 points. The field strength created by this forward power was recorded at each of the 9 points. By knowing the values for power and field strength, the power required to perform the calibration test can be calculated (for example, if 9 V/m corresponds to 81 W, then 3 V/m corresponds to 9 W). After GTEM calibration, all measurement data were stored in the calibration files and copied in a file for further use during immunity tests. After performing the plane calibration in the empty GTEM, the EUT was inserted with its front face coincident with the calibration plane and the values obtained from the calibration are used to generate the EM field.

B. Measurement Setup

Fig. 5 shows Setup for testing three-phase watt-hour meters inside GTEM cell. The immunity testing analysis is carried out by subjecting the smart meter system to threats considered by IEC 62052-11 [2] and following the test procedures prescribed in IEC 61000-4-3 [3]. For the purpose of this analysis and for testing under conditions as similar to the actual conditions of smart meter operation, we assumed that centralized metering operation system, communicate with two-way meters at the customer's premises and can send and receive messages over a wide area network (WAN), possibly using neighborhood area networks as well. All smart meter samples were tested in its normal working operation, so SIM card was inserted inside the GPRS module, and then the communication operation to control center was started by using the software program that referred to every smart meter model. Then smart meter can send and receive messages over the wide area network (WAN). So a communication link was established at the start of the test, and has to be maintained during the test. Smart meters were tested in three orientations (X-Y-Z) to ensure complete exposure to the generated electric field.

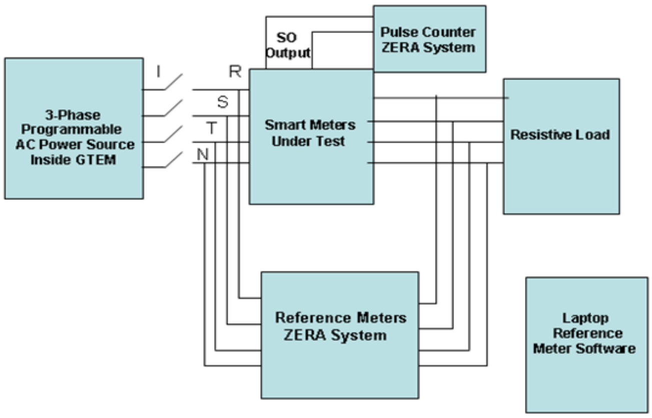

Fig. 5: Setup for testing three-phase watt-hour meters

The test was performed by applying an electromagnetic field of defined strength while varying the frequency in the range 80...1000 MHz. The instruments used for performing the tests were reported in Table 1. The values obtained from the calibration are used to generate the EM field. Every meter was tested in its normal operation (voltage circuits energized with reference voltage and without any current in the current circuits in case of applying 30 V/m and with nominal current at applied 10 & 3V/m according to IEC 62052-11 [2]). The meter was strapped to manipulator to assist with the rotations inside GTEM and the manipulator was placed in the center of the test volume as shown in Fig. 6. Un modulated test fields was applied from 30 V/m to 3 V/m while varying the frequency in the range 80…1000MHz and the frequency range was incrementally swept with a step size equal to the frequency of the previous step after multiplication by a factor of 1.01 (1% step size). The test was repeated 3 times for each sample. EUT operation was monitored throughout the test for any malfunction or degradation and its performance was recorded. The performance was identified through visual camera and the communication performance of a smart meter system under radiated electromagnetic disturbances was identified through software program that installed on PC of control center operation system by one of two cases: first, data connection and second, data disconnection (cutoff). All results were obtained for each sample and recorded as shown in table 2, 3, 4, and 5.

Fig. 6: DUT fixed on manipulator inside GTEM

C. Evaluation of Smart Meters' Accuracy

The responses of all samples to 30V/m, 10V/m and 3V/m are compared as shown in figures 7, 8, & 9. The readings were obtained from SO outputs using pulses counter, after which it was necessary to multiply the number of pulses by the corresponding constant of every meter. It is shown from these figures that when 30V/m was applied on all samples and when the connection to the wide area network (WAN) was ON all samples were hang, but when the connection to the wide area network (WAN) was OFF, unexpected nonexistent energy was registered by smart meter devices and for some samples, it constitute a change in the KWh register greater than admissible change.

At 10 V/m was applied on all samples and when the connection to the wide area network (WAN) was ON all samples were hang, but when the connection to the wide area network (WAN) was OFF, all samples exhibit an accuracy errors caused by applying electric field. These accuracy errors represent the change of error measured during test and when the meter is back at normal operating condition. The meters shall not present errors greater than admissible percent errors indicated on table 3. For meters class 0.5, errors shall not be greater than 1% and for meters class 1, errors shall not be greater than 2%. It can be said, on observing the results of the tests on smart meter samples (fig. 8), that the measurement error they exhibit under radiated RF electromagnetic fields (10 V/m) is minimal, and that their general performance is good. But poor tolerances of their components may induce accuracy errors that will become considerable measurement errors.

But when 3 V/m was applied and when the connection to the wide area network (WAN) was ON or OFF, smart meters offer a good performance and all meters function correctly as normal operation and the change of accuracy error caused by applying electric field was very low with respect to the accuracy error at normal operation. From the results of the testing of smart meters, it can be said that with applying 30 and 10 V/m, all samples were very sensitive to these disturbances and function not correctly with respect to function at normal operation.

Table 2 Effect of radiated RF electromagnetic fields at 30 V/m

change in the KWh register at			
	Comm. with smart meter ON	**Comm. with smart meter Off**	**Admissible change in the KWh register**
SM1	Hang	0.4 Wh	1.039 Wh
SM2		0.9 Wh	1.039 Wh
SM3		2.4 Wh	3.960 Wh
SM4		3.0 Wh	1.039 Wh
SM5		4.8 Wh	3.960 Wh
SM6		0.8 Wh	1.039 Wh
SM7		5.0 Wh	3.960 Wh
SM8		5.6 Wh	3.300 Wh
SM9		0.6 Wh	1.039 Wh

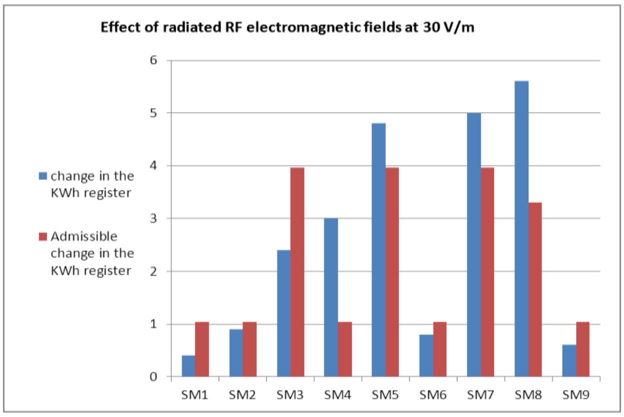

Fig. 7: Effect of radiated RF electromagnetic fields at 30 V/m

Table 3 Evaluation of accuracy of smart energy meters at 10 V/m

Maximum variation in error % at			
	Comm. with smart meter ON	**Comm. with smart meter Off**	**Admissible error**
SM1	Hang	+ 0.86 %	± 2 %
SM2		+ 0.94 %	± 1 %
SM3		+ 0.69 %	± 2 %
SM4		+ 0.37 %	± 1 %
SM5		+ 0.50 %	± 2 %
SM6		+ 1.60 %	± 2 %
SM7		+ 0.77 %	± 2 %
SM8		+ 2.82 %	± 2 %
SM9		+ 0.22 %	± 2 %

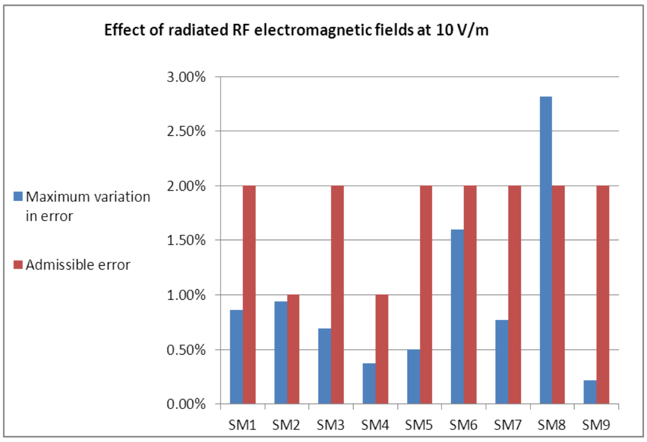

Fig. 8: Effect of radiated RF electromagnetic fields at 10 V/m

Table 4 Evaluation of accuracy of smart energy meters at 3 V/m

Maximum variation in error % at			
	Comm. with smart meter ON	Comm. with smart meter Off	Admissible error
SM1	Meter function correctly	+ 0.07 %	± 2 %
SM2		+ 0.10 %	± 1 %
SM3		+ 0.09 %	± 2 %
SM4		+ 0.07 %	± 1 %
SM5		+ 0.01 %	± 2 %
SM6		+ 0.02 %	± 2 %
SM7		+ 0.02 %	± 2 %
SM8		+ 0.01 %	± 2 %
SM9		+ 0.03 %	± 2 %

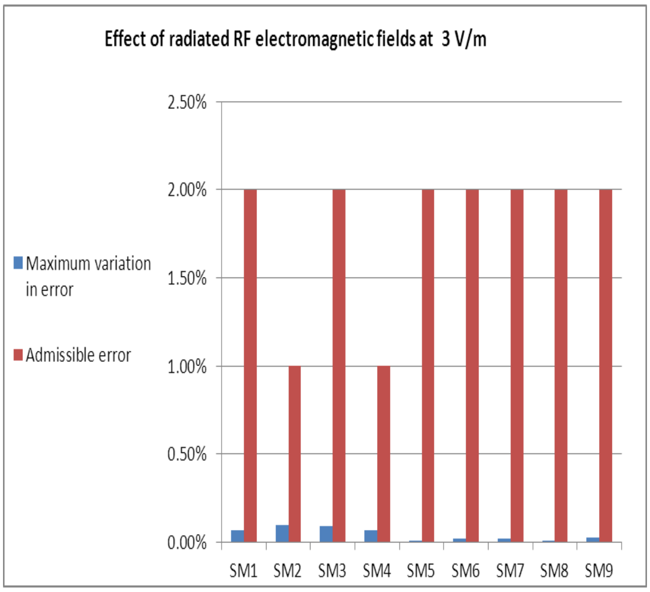

Fig. 9: Effect of radiated RF electromagnetic fields at 3 V/m

D. *The Impact of EMI on Smart Meters Network*

From table 5, all results for all samples showed that, the communication performance of smart meter systems was influenced much more by applying electric field greater than 3V/m and the communication to meters was cutoff in this range. Now we intended to prove these results analytically. Smart meter samples were equipped with a GPRS modem, and the communication takes place over the network of the mobile operator. During the immunity test, wanted and interfering signal was coupled to smart meter modem antenna input. If the interfering signal was strong enough, it is causing the first amplifier in the receiver LNA (low noise amplifier) to reach its compression point, thus causing a decrease in gain and potentially raising the amplifier's noise Figure. The corresponding ratio of unwanted signal in dB to the level of wanted signal in dB is noted the "Blocking" ratio. Blocking is defined as the degradation of receiver sensitivity in the presence of a much stronger (blocking) signal [16]. If the O/P of the receiver has these strong unwanted signals in close proximity to the desired signals, they cause the receiver to lose sensitivity to the desired signal. The blocking signal level which a GSM/GPRS modems is expected to perform without dropping a connection equal to -5 dBm [17].

Table 5 Evaluation the communication performance of a smart meter system under radiated electromagnetic disturbances

Applied Electric Field (V/m)	Communication with smart meter	
	ON	*Cutoff*
30		√
20		√
10		√
9		√
8		√
7		√
6		√
5		√
4		√
3	√	

Unwanted signal during immunity test analysis is the power received due to applied electric field at the O/P of DUT inside GTEM. So if we can calculate this power received and compare to the blocking signal limit of GPRS (-5dBm), we can determine the limits of applied electric field that make the data connection between smart meter and control center cutoff. According to ANSI/SCTE 48-1 2007 [18], the power received at O/P of DUT inside GTEM can be calculated from the equation below.

$$P_r = \frac{E^2 G_r \lambda^2}{480 \pi^2}$$

Where

P_r = Received power at output of DUT
E = Field strength (V/m)
G_r = Gain of receiving antenna
λ = Wavelength (m)

From this equation, and for receiving antenna with G_r = 1dBi, there is a direct relation between frequency and received power at O/P of DUT inside GTEM for certain applied electric field value. Fig. 10 show the variation of power received P_r with frequency f (MHz) at different applied electric field values (30 V/m to 3 V/m). It is evident from this Fig. that the power received in frequency range 80 MHz to 1000 MHz exceeds the blocking level (-5 dBm) by different values for all applied electric field from 30 V/m to 4 V/m, so all these values of power received cause the smart meter to hang and get cutoff of data connection. But at frequency range from 80 MHz to 750 MHz for applied electric field 3 V/m, the power received exceeds the Blocking level (-5dBm) and for frequency greater than 750MHz, the power received has value lower than the blocking level (-5 dBm), so the communication between smart meter and control center does not cutoff and the data connection was continued.

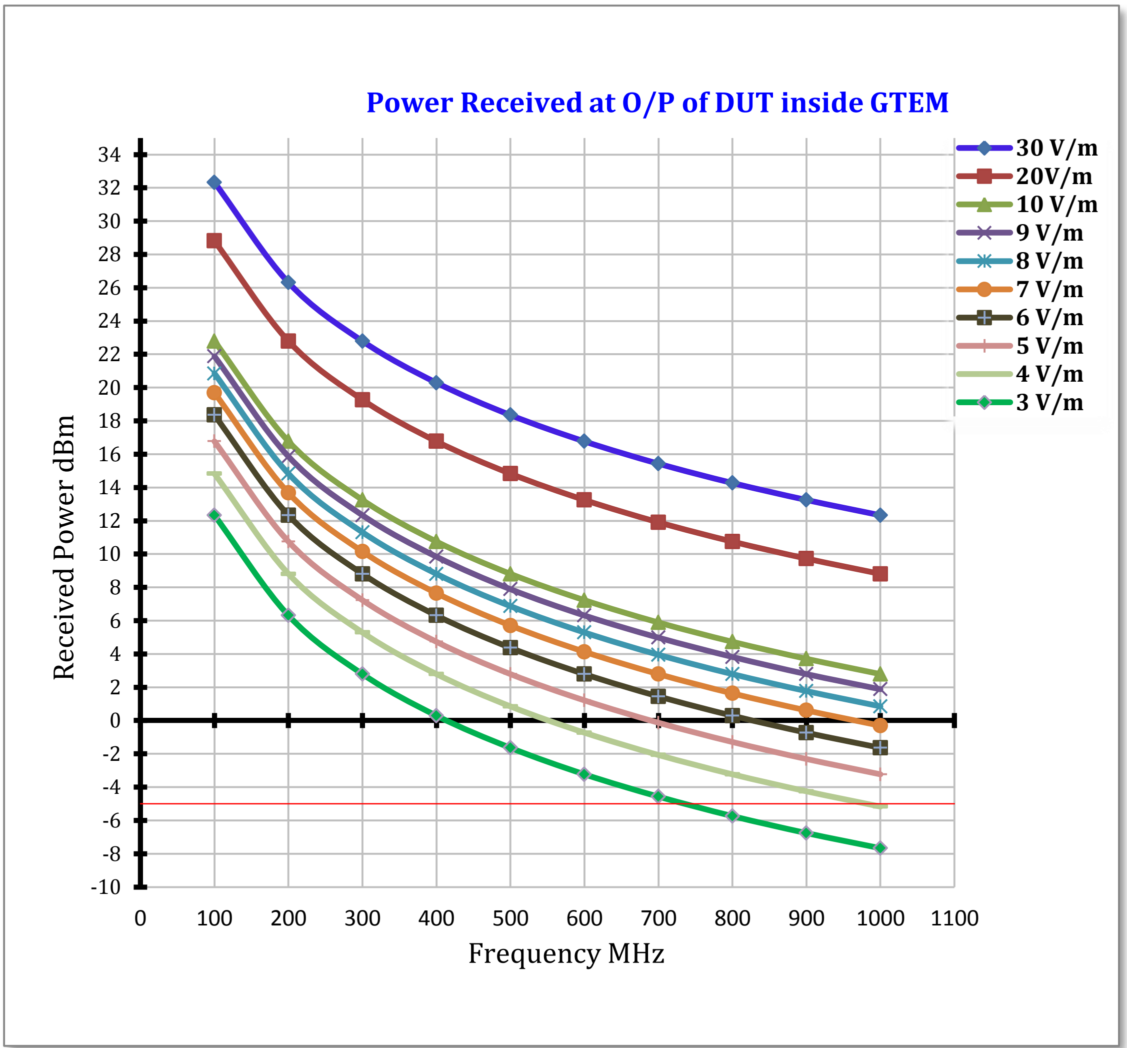

Fig. 10: Power received at o/p of DUT inside GTEM at (3 – 30 V/m)

As shown in table 5 and Fig. 10, the results of measurements lead to the same results of the theoretical analysis. So the communication performance of smart meter system was much more affected by applying electric field greater than 3 V/m and the data connection was cutoff. On the other hand by applying electric field equal to 3 V/m in frequency range 800 MHz to 1000 MHz, a communication link that was established at the start of the test, does not cutoff and data connection was maintained during and after the test.

After performing immunity testing, it was essential to judge whether the EUT had in fact passed or failed the test. According to the IEC 61000-4-3, the test results can be classified on the basis of operating conditions and the functional specifications of the DUT according to the criteria specified by the manufacturer. Any smart meter device will have a noise threshold that if exceeded, it will cause failure. The failure usually will occur in these four categories:

1.DUT fails momentarily, and then corrects itself (criterion A)

2.DUT fails and interrupt or reset recovers DUT (criterion B)

3.DUT fails. Powering OFF then ON recovers the failure (criterion C)

4.DUT fails and permanent damage (criterion D)

If the failure occurs in categories 1 and 2, then it may go unnoticed and the end user may either never see the failure or accept it due to its irregular occurrence. However, if the failure is in categories 3 or 4, then it definitely will be seen as an immunity problem and will be unacceptable by any manufacturer.

According to the analysis of the results and to the immunity-related standards, the traditional electronic energy meter was tested for applied field 30 and 10 V/m and the obeying of the criterion B was analyzed. According to this criterion, the DUT was supposed to maintain its operational state at the rated parameters during the test and after it. No modification of the parameters was allowed during the test and after it (DUT recovers its performance without intervention). But smart meters samples were tested for applied field from 30 V/m to 3 V/m. The obeying of the criterion C was analyzed (temporary loss of function or degradation and requiring intervention). So the results showed that all samples were not obeying the criterion B (that specified for traditional electronic meters in IEC) for applying electric field more than 3 V/m. On the other hand, all samples obeyed the criterion B at applied electric field equal to or less than 3 V/m.

IV. CONCLUSION

In this paper, the evaluation of the smart meter's immunity to radiated electromagnetic interference has been analyzed. A gigahertz transverse electromagnetic (GTEM) cell was used as a simple piece of measurement equipment to evaluate the response of smart meter system exposed to electromagnetic field radiation under conditions approximating free space. The results showed that, deleterious effects of EMI can prevent a smart meter from accurately reading and reporting energy consumption, or they could even provide users with misleading information about energy usage.

The demand for reviewing EMC test standards for electronic energy meters becomes utmost necessity. To perform radiated immunity test for smart meters, the RF immunity requirements have to extend beyond the 30 and 10 V/m levels, to be 30, 10, and 3 V/m. Smart meter systems should be tested under conditions as similar to the actual conditions of their operation as possible.

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