

# Harmonic Distortion During the 2010 FIFA World Cup

P. F. Ribeiro, *Fellow*, IEEE, J. J. A.L. Leitão, *Member*, IEEE, M. M. S. Lira, *Member*, IEEE, J. R. Macedo Jr, *Senior Member*, IEEE, A. L. Z. Grandi, A. Testa, *Fellow*, IEEE, R. Langella, *Senior IEEE*, J. F. G. Cobben, *Member*, IEEE, N. R. Browne, *Member*, IEEE

**Abstract**—This paper presents harmonic distortion measurements in several countries taken during live televised matches of the 2010 Soccer World Cup held in South Africa. The paper provides an analysis of the components involved in the increase of total harmonic distortion of current and voltage. The work also compares the latest measurements with previous events and makes some considerations regarding future trends. Measurements from Brazil, Italy, Netherlands and Australia are presented and briefly discussed. Lessons learned from these observations could potentially improve our understanding of the impact of customer equipment and customer behavior on harmonic levels and assist in managing waveform distortion now and in the future.

**Index Terms**—harmonic distortions, soccer world cup.

## I. INTRODUCTION

Harmonic distortion is still a significant power quality concern. Although harmonic problems are not very prominent on utility systems, they occur from time to time and can cause severe disturbances. When harmonic currents produced by nonlinear loads are injected back into the supply systems, harmonic currents and voltages can be amplified and adversely affect a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating and overloading. These harmonic currents can also cause interference with telecommunication lines and errors in power metering.

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J. J. A.L. Leitão is an engineer with San Francisco River Hidroelectric Company-CHESF, the main generation and transmission company in the Northeast of Brazil (e-mail: julio@chesf.gov.br).

M. M. S. Lira is an adjunct professor of the Federal University of Pernambuco (UFPE), Brazil (e-mail: milde@ufpe.br). N. R. Browne is an engineer with Integral Energy, one of the Australian distribution utilities. (email neil.browne@integral.com.au.)

A. Testa, is a full professor at the Second University of Naples, Italy. (alfredo.testa@unina2.it)

R. Langella, is an associate professor at the Second University of Naples, Italy, (roberto.langella@unina2.it)

J. R. Macedo Jr. is an adjunct professor at the Power Quality Group of the Federal University of Uberlândia, Brazil (e-mail: jrubs@ieee.org).

A. L. Z. Grandi is currently working at Bandeirante Energia - EDP Group, (e-mail: andre.grandi@edpbr.com.br)

J. F. G. Cobben is currently working at Alliander, one of the Dutch distribution network operators and as a part-time assistant professor at the EES group of the Eindhoven University of Technology, The Netherlands, (e-mail: j.f.g.cobben@tue.nl).

P. F. Ribeiro is an associate professor at the EES group of the Eindhoven University of Technology, The Netherlands, (e-mail: p.f.ribeiro@tue.nl).

Harmonic distortions on the power grid can become more severe on some occasions when there is a significant event happening at a certain time such as a world cup soccer game or other high rating television events.

In a paper published in 1987 [1] distortion levels for the 5<sup>th</sup> harmonic in the 230kV transmission system showed a significant increase during the period of a game of the Brazilian national team at FIFA World Cup of 1986. During the 2006 World Cup, measurements were taken at several locations and presented at the 2007 IEEE PES Summer Meeting Panel Session [2], [3], [4], [5]. Since then additional measurements have been taken during other major televised events including world cup games. This paper presents additional measurements taken in four different countries during the 2010 FIFA World Cup.

## II. MEASUREMENT RESULTS

### A. Brazil - Southeast (Distribution Systems)

Measurements presented in this section were taken at a 13.8kV substation in a suburban area of Southeast Brazil. The measurements showed a significant decrease in the fundamental current level during game broadcasts. The decrease in the fundamental current contributed to the percentage increase in the current THD which also reflected on the voltage for the 5<sup>th</sup> harmonic. As expected a considerable increase of the 5<sup>th</sup>, 7<sup>th</sup> and 11<sup>th</sup> harmonic voltages were also observed.

Figure 1 shows the voltage THD during the Brazil versus South Korea Game and the variation related to a normal working day. Figure 2 shows the THD at different days including times of the games of Brazil. Figure 3 illustrates the harmonic voltage distortion (3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup>)— During a game and also on a normal day. The distortion reduction at half-time break seems to be caused by a temporary increase in the load demand which causes a damping and lower system impedance at the harmonic frequencies.

### B. Brazil – Northeast (Transmission Systems)

Measurements were taken at several substations. Figure 4 shows the 5<sup>th</sup> harmonic voltage at Fortaleza 230kV (Northeast of Brazil) on June 25, 2010, during the Brazil versus Portugal game. Typical 5<sup>th</sup> harmonic voltage on normal day is below 0.5% for the 230kV system (see Figure 5).

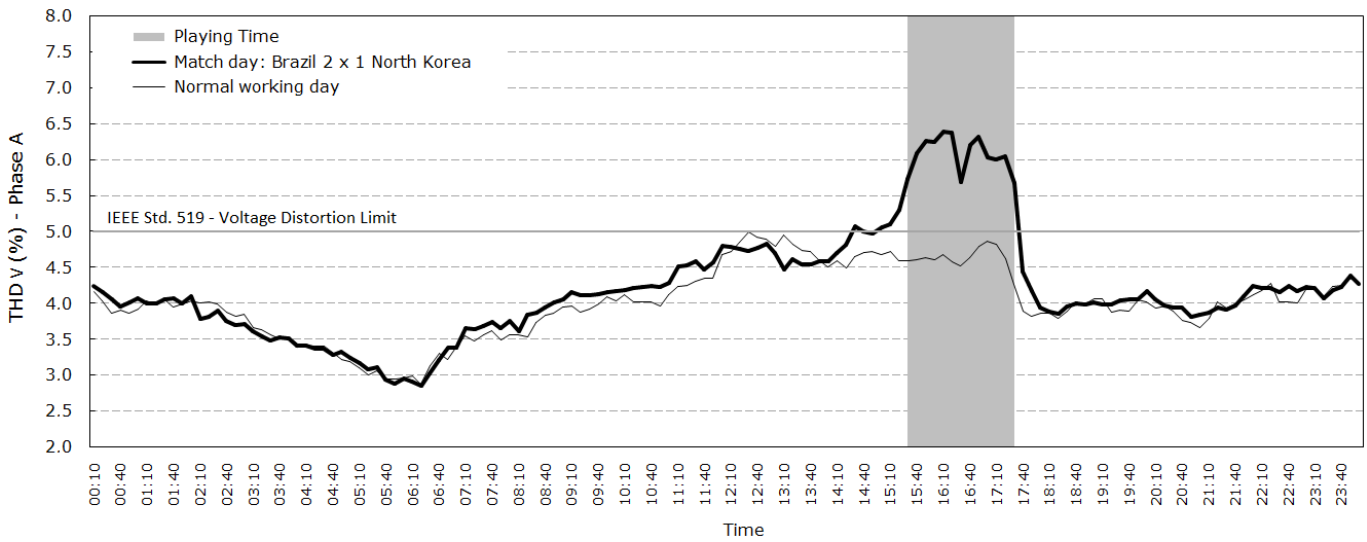


Figure 1 – Voltage THD at distribution bus during the match Brazil x North Korea and during a normal day

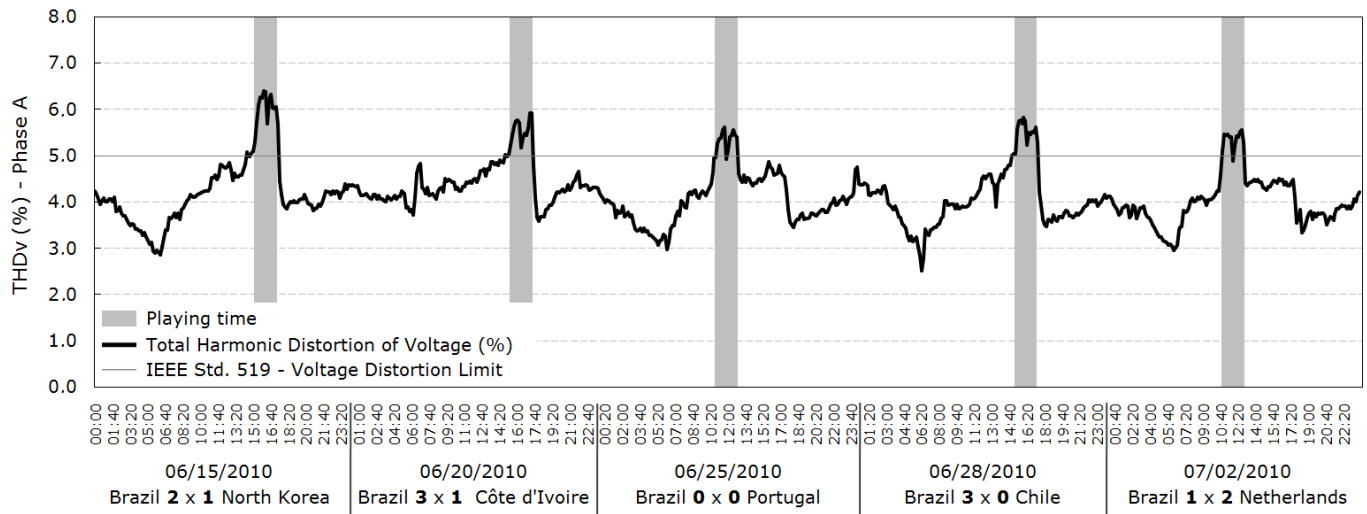


Figure 2 - Voltage THD at different days including time of the games of Brazil

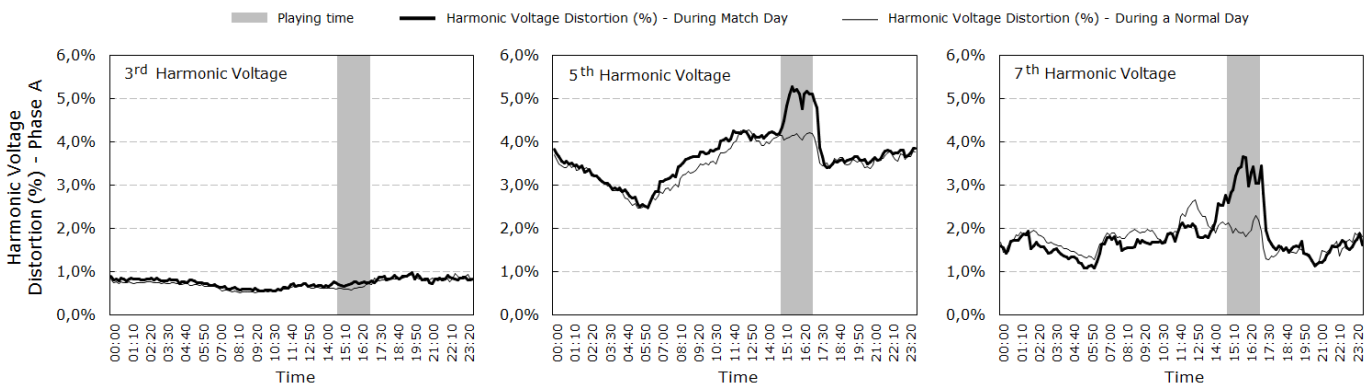


Figure 3 - Harmonic Voltage Distortion (3<sup>rd</sup>, 5<sup>th</sup> and 7<sup>th</sup>) – During a game and on a normal day.

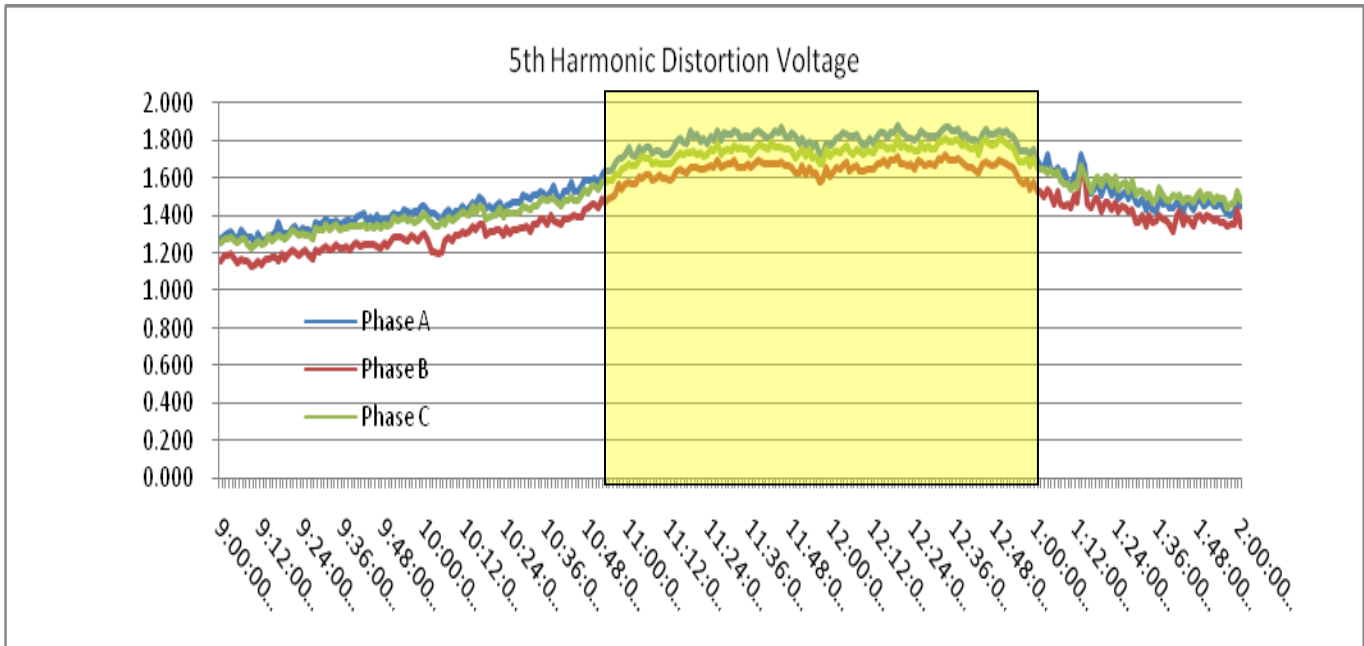


Figure 4–Harmonic voltage distortion (5<sup>th</sup>) at Fortaleza 230kV during a game of the Brazilian national team

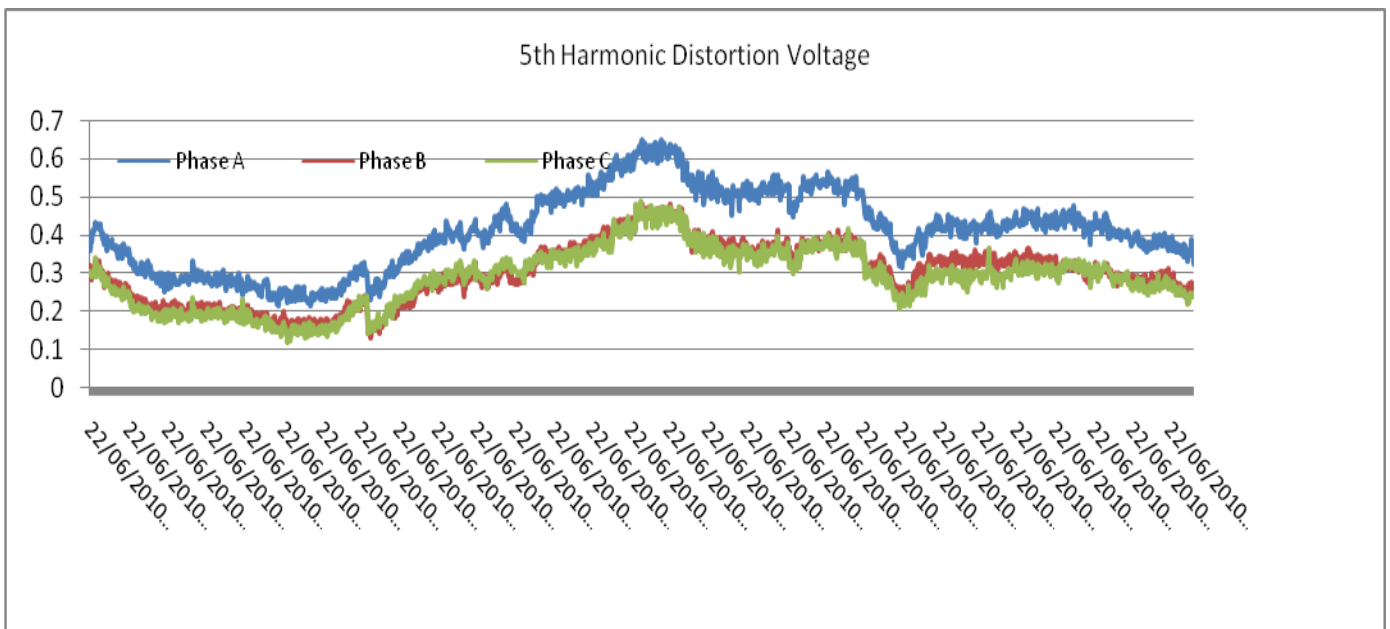


Figure 5 - Harmonic voltage distortion (5<sup>th</sup>) at Fortaleza 230kV during a normal day

### C. Italy - (Residential / Distribution System)

Measurements were performed on a LV residential substation for four weeks from the 14th of June 2010 to the 11th of July 2010. Figure 6 reports the results obtained during the match Italy vs. Slovak Republic (continuous lines) on June 24th from 16:00 to 17:45, and the results obtained during the same hours of the same day of the previous (June 17th). Figure 8 reports

the voltage THD (Fig. 8a) and fifth harmonic voltage,  $V_5$ , as percentage of  $V_1$  (Fig. 8b). All the values reported are obtained as mean values each two minutes.

It is possible to observe that, during the match, both the voltage THD and fifth harmonic are higher than the corresponding hours of the previous week. Moreover, at the end of the match the THD starts approaching the amplitude of the previous week.

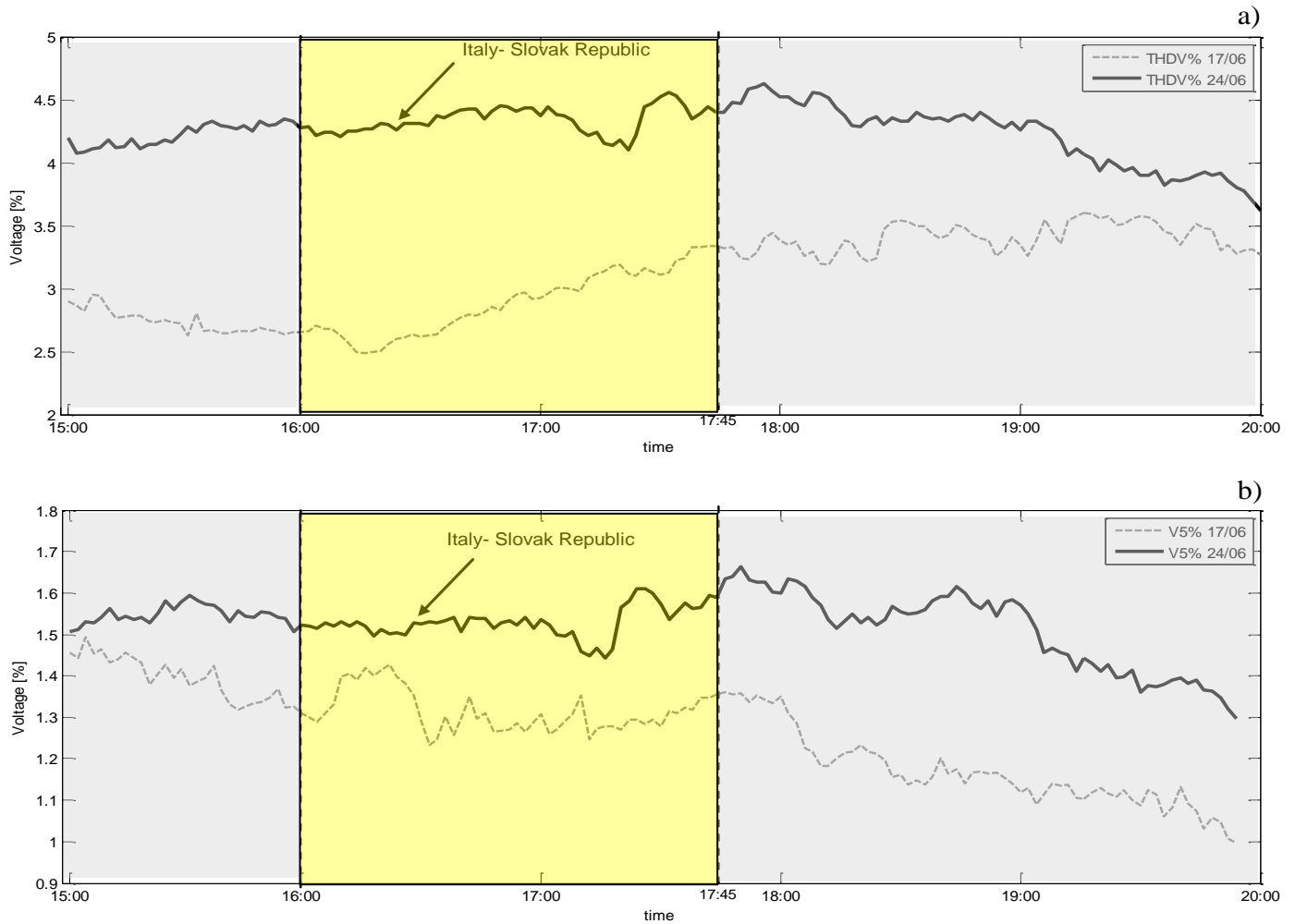


Figure 6: Harmonic voltage (THDV (a) and 5<sup>th</sup> (b)) for the same day of two different weeks - 17th (dashed lines) and 24th (continuous lines – Italy vs Slovak Republic) of June 2010.

#### D. The Netherlands (Residential / Distribution System)

Measurements were taken at the Bronsbergen 400V. Figure 7 shows the voltage THD for several weeks. No typical changes were observed during the day of the final between the Netherlands and Spain. Figure 8- shows the voltage THD Nijmegen 10kV bus. Also no significant differences were observed.

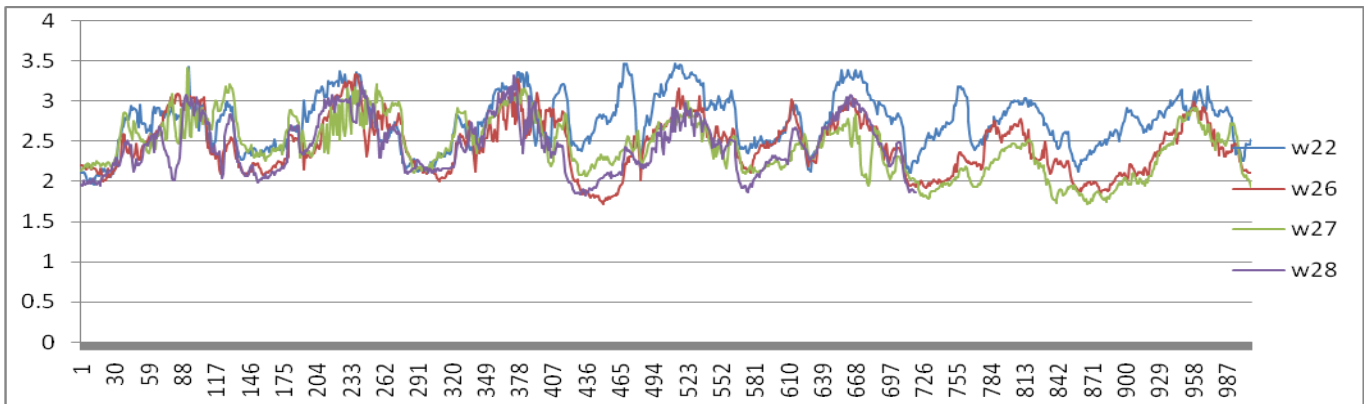


Figure 7 – Harmonic voltage THD at the Bronsbergen (average of 10 minutes) 400V bus over a week (for several weeks) including the week / day of the final game

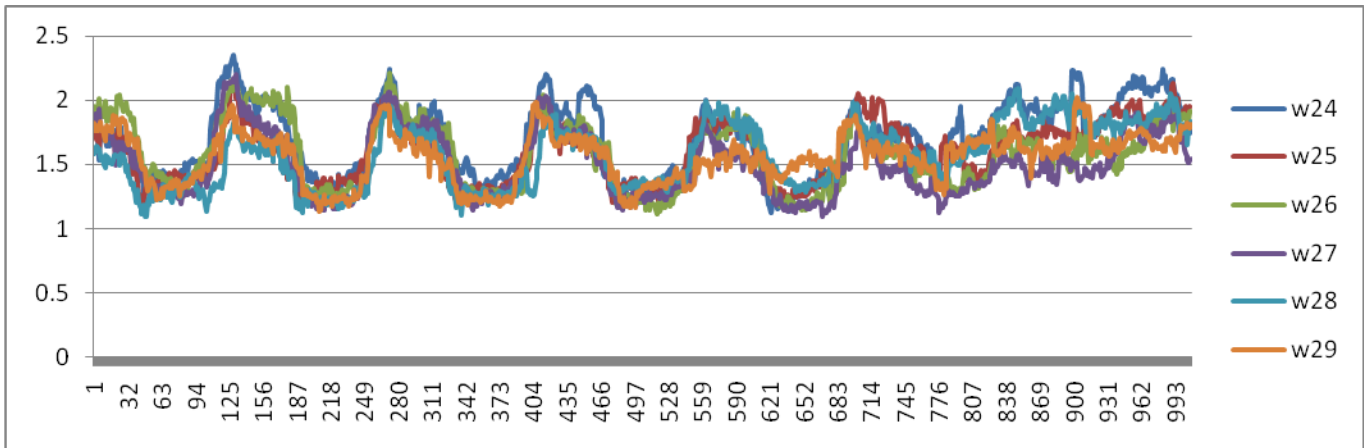


Figure 8 - Harmonic voltage THD (average of 10 minutes) at the Nijmegen 10kV bus over a week (for several weeks –w24-w29) including the day of the final game.

### E. Australia – Eastern (Distribution System)

Fifth harmonic voltage measurements covering the period of the 2010 World Cup are shown for 4 11kV sites in the Sydney area, in Fig 9. The viewing times for some of the more closely watched matches are summarized below:

Date/Time	Match	Group
14/06/2010 4:30	Germany v Australia	D
20/06/2010 0:00	Ghana v Australia	D
24/06/2010 4:30	Australia v Serbia	D
7/07/2010 4:30	Uruguay v Netherlands	S-Final
12/07/2010 4:30	Netherlands v Spain	Final

Whilst 5th harmonic voltages varied at each site over the month, no significant changes coincident with world cup matches were discernable. The world cup final was seen in Sydney at 0430 on Monday 12th July. 3rd, 5th and 7th harmonic voltages and THD at one 11kV site for the period of the final match are shown in Fig 10. The total apparent power is also shown in this graph, indicating the network was lightly loaded during the match. The apparent power shows the daily load pattern for a residential area with marked changes due to programmed switching of storage domestic water heaters. No impact on harmonic voltages attributable to the increased television viewing in the early morning is discernable.

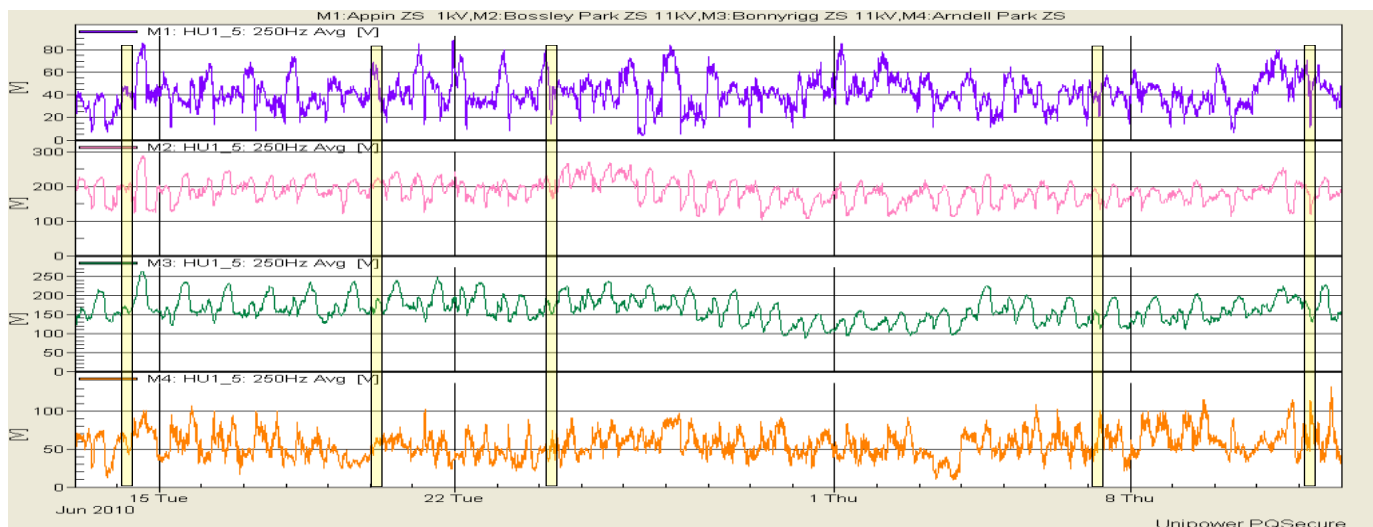


Figure 9 - Fifth harmonic voltage measurements covering the period of the 2010 World Cup are shown for 4 11kV sites in the Sydney area

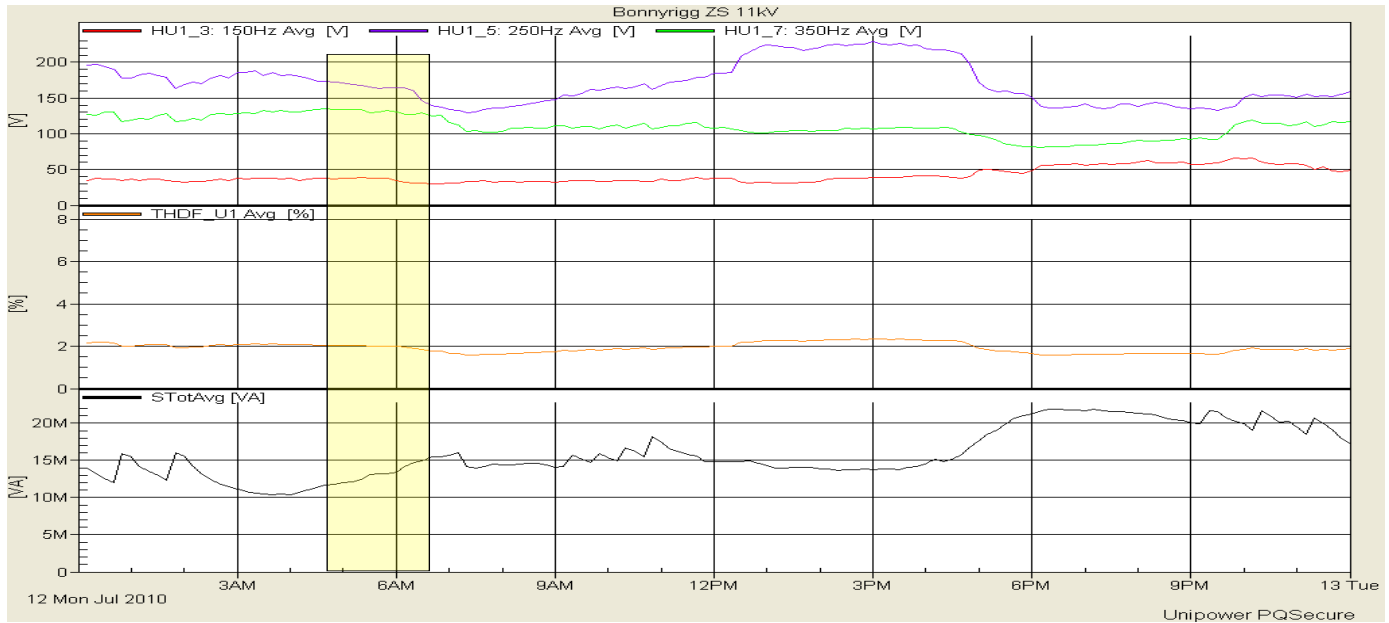


Figure 10 – The world cup final was seen in Sydney at 0430 on Monday 12th July. 3rd, 5th and 7th harmonic voltages and THD at one 11kV site for the period of the final match

### III. PREVIOUS RESULTS AND FUTURE TRENDS

#### Brazil

Figure 11 shows the measurements of the 5<sup>th</sup> harmonic voltage on a 230kV bus where the impact of the televised world cup of 2006 can be seen. Figure 12 shows the voltage THD for a 130kV bus for similar events during the 2006 and 2010 world cups. Although the system impedance may have varied during the two events, the general results show a clear correlation.

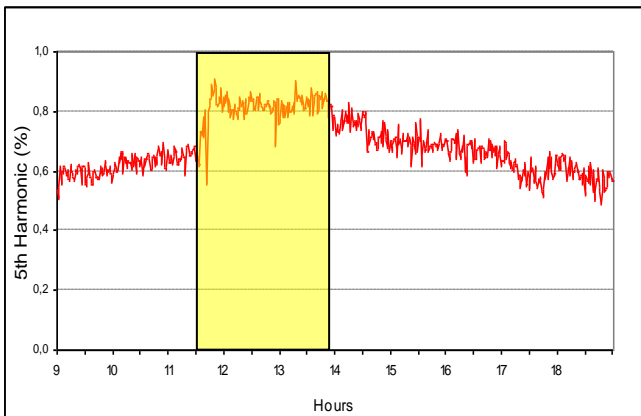


Figure 11 – Measurements Fortaleza 230kV – 2006 World Cup

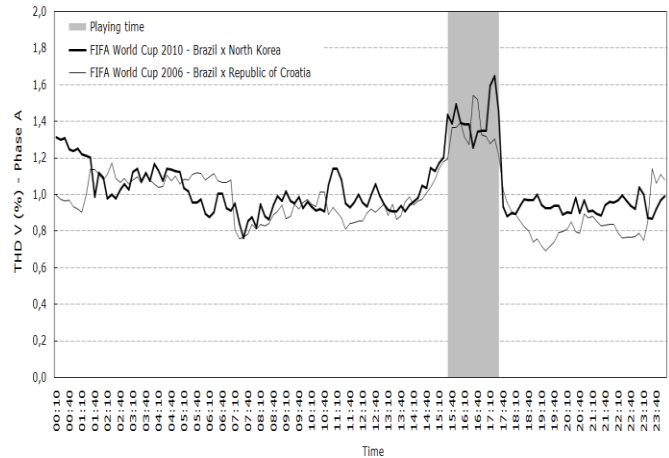


Figure 12 – Harmonic voltage distortion 130kV bus – during the world cup 2006 and 2010 games

#### Italy

Figure 13 reports the fifth harmonic voltage during the six hours including the final match of the Word Cup 2006 Italy-France [5], from 18:00 to 24:00 of Sunday, July 9-th, together with the results obtained in the same hours the Sunday of the week before, July 2-nd. A very similar behavior to that of Figure 7b) can be appreciated.

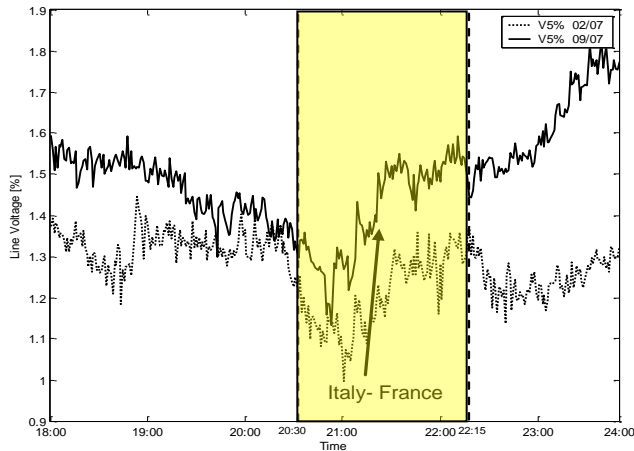


Figure 13: Harmonic voltage V5 [% of  $V_1$ ] of the 2-nd (dotted lines) and 9-th (continuous lines – Italy vs France) of July 2006..

### Australia

The 3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup> harmonics and THD were checked for the 2006 Australia v Brazil match at 0200 on 19 June. The harmonic levels were very similar to those recorded for the 2010 final. Some reduction can be observed in the 3<sup>rd</sup> harmonic voltage levels at the site since 2006 - See Figure 14

## IV. CONCLUSIONS

The Impact of Television Viewing on the Utility Grid Harmonic Distortion has been considered. Measurements during of 2010 FIFA World have once again shown, for some systems, a significant increase of harmonic pollution during the televised games, particularly the fifth harmonic.

In Brazil, for both the transmission and distribution system considered, a significant increase in the level of distortion was observed during the broadcast of the games.

Measurements for the Australia system and the Netherlands showed little impact. The time of the game in Australia and the heavy and densely loaded Dutch networks may have been the cause of the little impact on the harmonic distortion.

The Italian distribution system considered also showed a good correlation of the harmonic distortion levels.

Considering the measurements taken in the last several years, it can be seen that the harmonic distortion levels can have a strong correlation with television viewing for certain systems, but that the levels remained relatively stable.

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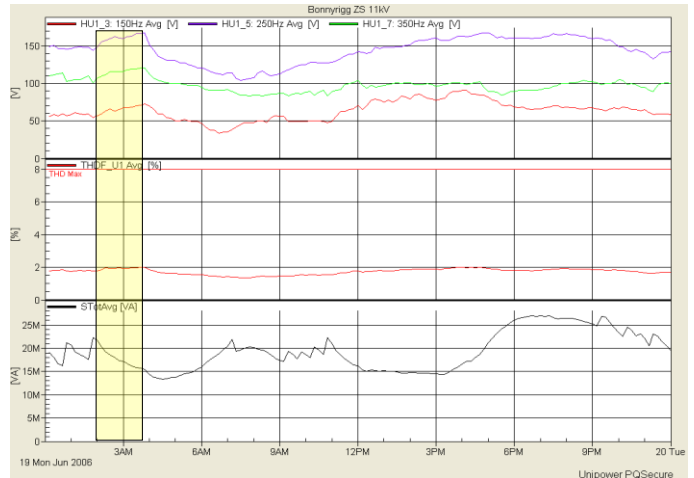


Figure 14 - The 3<sup>rd</sup>, 5<sup>th</sup>, 7<sup>th</sup> harmonics and THD were checked for the 2006 Australia v Brazil match at 0200 on 19 June

**Paulo F. Ribeiro** (M'79, SM'88, F'03) Received Ph.D. from the University of Manchester, Manchester, UK. He is an Associate Professor of Electrical Engineering at the Technical University of Eindhoven, Eindhoven, The Netherlands. His research interests include power electronics, power quality, system modeling and simulation.

**Alfredo Testa** (M'83–SM'03–F'08) was born in Naples, Italy, on March 10, 1950. He received the degree in electrical engineering from the University of Naples, Naples, Italy, in 1975. Currently, he is a Professor in Electrical Power Systems at the Second University of Naples, Aversa, Italy. He is engaged in research on electrical power systems reliability and harmonic analysis. Dr. Testa is a Fellow Member of the IEEE Power Engineering Society and the Italian Institute of Electrical Engineers (AEI).

**José R. Macedo Jr.** (M'05, SM'08) Received B.Sc. and M.Sc. from the Federal University of Uberlândia, Brazil, and D.Sc. from Federal University of Espírito Santo, Vitória, Brazil. He is an Adjunct Professor of Electrical Engineering at the Federal University of Uberlândia, Brazil. His research interests include power electronics, power quality, system modeling and simulation.

**A. L. Z. Grandi** is currently working at Bandeirante Energia, one of the Brazilian electrical utilities. At present, he is in progress with his Master Degree at University of São Paulo, São Paulo, Brazil.

**Roberto Langella** (S'00–M'01–SM'10) was born in Naples, Italy, on March 20, 1972. He received the electrical engineering degree from the University of Naples, Naples, Italy, in 1996, and the Ph.D. degree in electrical energy conversion at the Second University of Naples in 2000. Currently, he is an Associate Professor in Electrical Power Systems at the Second University of Naples, Aversa, Italy. He is a Senior Member of the IEEE Power Engineering Society.

**Sjef Cobben** received the Bachelors degree in Electrical Engineering from the Technical University of Heerlen in 1979. In 2002 he received the Masters degree in Electrical Engineering from TU/Eindhoven. Since 2000 he is working for the Dutch grid operator Alliander, where he is engaged in Power Quality problems and safety requirements. In 2007, he completed his Ph.D. project about "intelligent grids" with as special topic Power Quality problems. He is author of several books about low voltage installations and power quality. Since 2008 he is assistant professor at the University of Eindhoven in EES (Electrical Energy Systems).

**José Julio A. Lins Leitão** received Ph.D. degree in electrical engineering from University of São Paulo (USP), São Paulo-Brazil. He has been working for San Francisco River Hydroelectric Company-CHESF, at present in Protection and Automation. His research interests include electric power quality, system modeling and simulation, protection performance and disturbance analysis. He is a member of International Council on Large Electric Systems (CIGRÉ).

**Milde Maria da Silva Lira** received Ph.D. degree in electrical engineering from Federal University of Pernambuco (UFPE), Recife-Brazil. She is an

Adjunct Professor of Electrical Engineering at the Federal University of Pernambuco (UFPE). Her research interests include wavelets, artificial neural networks, fuzzy intelligent system and electric power quality.

**Neil Browne** is an engineer with Integral Energy's Strategic Asset Management Branch. He received his Bachelor of Engineering Degree from the University of New South Wales in 1976. He is involved in protection policy, operational analysis and power quality control and monitoring. Mr. Browne is a Chartered Professional Engineer in Australia.