Rev. Roum. Sci. Techn.– Électrotechn. et Énerg.
Vol. 63, 2, pp. 123–127, Bucarest, 2018

Électrotechnique et électroénergétique

Dedicated to the memory of Academician Andrei Țugulea

ON PROFESSOR ȚUGULEA'S VISIONARY POWER THEORY: A REVIEW, RECENT ADVANCES AND PERSPECTIVES

RADU MIRCEA CIUCEANU, IOSIF VASILE NEMOIANU, VERONICA MANESCU (PALTANEA), GHEORGHE PALTANEA

Key words: Professor Țugulea power theory, Professor Budeanu power theory, Three-phase circuits, Unbalanced load, Nonlinear (distorting) load, Symmetry active power, Non-symmetry active power, Residual (distortion) active power, Symmetry reactive power, Non-symmetry reactive power, Residual (distortion) reactive power, Circuit simulation, Power grid.

The main goal of the paper is to review the most important aspects of Professor's Andrei Țugulea power theory as they were formulated by its author in a series of articles and studies starting from mid 1980's up to mid 1990's. Also, the paper proposes to put in today's perspective the main features and opportunities presented by this exceptional theory, by summarizing the most recent advances and developments in that field. Firstly, the essential characteristics of the power theory reside on the observation that unbalanced three-phase loads, energized from a supposedly symmetrical voltage system, pollutes the grid by reinjecting active power on the inverse and homopolar sequences, along with current harmonics. Secondly, a similar behavior was demonstrated for a nonlinear (distorting) three-phase consumer connected to a symmetrical power grid. These two components make up the core of Professor Țugulea's theory, which demonstrates that the existence of such a three-phase consumers (having both shortcomings) produces unnecessary active power circulation throughout the power grid with additional losses, including in energy billing overcharges for the balanced and linear consumers. More recently, efforts have been made to generalize the theory, initially formulated for an idealized power grid comprising a symmetrical ideal power generator, a linear balanced consumer and an unbalanced nonlinear load (The power line was supposed to be also linear and balanced). A general assessment of the opportunities offered by the theory in today's electric energy consumption profiles and grid characteristics is performed and, finally, appropriate conclusions are drawn.

1. INTRODUCTION

One of the most important contributions of Professor Andrei Țugulea's scientific legacy is represented by the power theory he has founded in the mid 1980's [1–5]. At that time, power electronics became one important factor for current and, consequently, voltage harmonic pollution throughout power grids, adding to the "classical" industrial sources of the sort: electric arc furnaces, electric motors *etc*.

Today's consumer profiles are more susceptible to contain nonlinear circuits elements even at a household level. Excepting the classical home appliances (refrigerators, washing machines, microwave ovens *etc*.) more nonlinear devices make up an average domestic consumption package: PCs, TVs and LCD displays, energy saving bulbs, LED lighting, chargers and power adapters *etc*. Consequently, despite their small rated power, the distorting effect of such devices cannot be ignored anymore, not only from the perspective of the unwanted upper harmonics injected into the grid (and associated degradation inflicted on power quality), but also from the perspective of energy billing, as demonstrated by Professor Țugulea's theory. Currently, numerous strategies addressing this issue are proposed and considered for a better power grid operation and management [6–11].

In that respect, on a simplified power grid model it was proven that an unbalanced and distorting consumer, similar to the above-mentioned ones, absorbs more active power as it would normally need and reinjects back into the grid a fraction of it thus inducing additional losses to the line.

Similarly, the balanced linear consumer also receives some additional unnecessary active power which translates to additional active energy to be billed. This disparity can be properly addressed as some rather basic computation capabilities would be integrated into the common active energy counters. That would require integrating a rather basic digital signal processor (DSP) programmed to compute the fast Fourier transform (FFT) for obtaining the voltage and current harmonics and then to perform the Fortescue theorem [12] of the first harmonic (fundamental) of these two signals.

Section 2 is dedicated to summarizing the main elements of Professor Andrei Țugulea's power theory, in what concerns the initially adopted power grid model and characteristics. Correspondingly, the outline of the theoretical background is presented, on which rests the whole power definition structure and associated calculations and their consequent practical interpretation.

Section 3 presents a preliminary grid model intended to generalize the original theory. Some useful conclusions are highlighted for the case when two unbalanced nonlinear loads are present in the grid, from the perspective of the powers summarized in Section 1.

Section 4 tries to identify the future possible development of the subject in order to provide an useful theoretical support for modern power grids analysis, assessment, and fair energy cost distribution among consumers.

Section 5 is dedicated to the final conclusions for the present review.

2. SUMMARY OF THE THEORY

In order to present the conceptual aspects of the power theory under scrutiny concerning steady-state three-phase networks, the following basic elements are to be considered:

- Tellegen's theorem [13] ensuring the conservation of instantaneous, active, reactive and complex powers (a direct corollary of the first and second Kirchhoff's circuital theorems [12]);

"Politehnica" University of Bucharest, Faculty of Electrical Engineering, Department of Electrical Engineering, 313 Splaiul Independenței, 060042 Bucharest, Romania, E-mail: iosif.nemoianu@upb.ro.

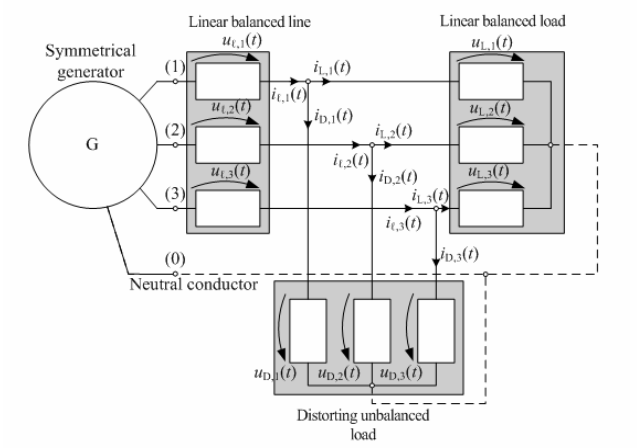

Fig. 1 – Simplified model of a three-phase network (with/without neutral) comprising a symmetrical generator, a linear balanced transmission line, a linear balanced load and a distorting (nonlinear) unbalanced load.

- Budeanu's reactive power definition [14], which present the useful characteristic of being conservative;
- Fourier series decomposition of the time-periodic signals of voltage and current waveforms;
- Fortescue theorem decomposition of the first harmonic of voltages and currents.

One essential aspect of the theory is quite often insufficiently understood or maybe overlooked, as highlighted in [3]. Active, reactive and complex power conservation is ensured by the validity of Kirchhoff's circuital theorems on each harmonic, regardless of the linear/nonlinear character of the elements components of the network. For the same reasons, these power conservation is also valid within each symmetrical component resulted from Fortescue's theorem decomposition (*i.e.* positive, negative and zero sequences), also valid independently from the specificity of the network consumers. In particular, active, reactive and complex power conservation takes place on each sequence of the fundamental harmonic. These observations represent the foundation of Professor Ţugulea's power theory, with important practical implications.

Initially, the considered three-phase grid model, shown in Fig. 1, was relatively simple and comprised only four elements, as follows [1–5]:

- a symmetrical purely sinusoidal power generator (index 'G');
- a linear balanced transmission line represented with lumped elements (index 'ℓ');
- a linear balanced load (index 'L');
- a distorting (nonlinear) unbalanced load (index 'D').

Note that the three-phase network depicted in Fig. 1 corresponds to either case (with/without neutral conductor, which is drawn in a dashed line). The following notations have been used in Fig. 1, in which the voltages are associated to the currents using the passive sign convention:

- $u_{a,k}(t)$ – the phase voltages, where the element index is $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ and the phase index is $k \in \{1, 2, 3\}$;
- $i_{a,k}(t)$ – the phase currents, with $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ and $k \in \{1, 2, 3\}$.

The phase voltages provided by the symmetrical generator can be written as

$$\begin{cases} u_{10}(t) = U\sqrt{2}\sin\omega t \\ u_{20}(t) = U\sqrt{2}\sin(\omega t - 2\pi/3) \\ u_{30}(t) = U\sqrt{2}\sin(\omega t + 2\pi/3) \end{cases}, \tag{1}$$

where U is the rms value of phase voltages and ω the angular frequency. Their corresponding complex phasors are $\underline{U}_{10}$, $\underline{U}_{20}$ and $\underline{U}_{30}$. Further notations are used for voltages and currents:

- $\left\{u_{a,1}^{(1)}(t), u_{a,2}^{(1)}(t), u_{a,3}^{(1)}(t)\right\}$ with $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ are the fundamental harmonic phase voltages of complex phasors $\left\{\underline{U}_{a,1}^{(1)}, \underline{U}_{a,2}^{(1)}, \underline{U}_{a,3}^{(1)}\right\}$;
- $\left\{i_{a,1}^{(1)}(t), i_{a,2}^{(1)}(t), i_{a,3}^{(1)}(t)\right\}$ with $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ are the fundamental harmonic phase currents of complex phasors $\left\{\underline{I}_{a,1}^{(1)}, \underline{I}_{a,2}^{(1)}, \underline{I}_{a,3}^{(1)}\right\}$;
- $\left\{\underline{U}_a^{[d]}, \underline{U}_a^{[i]}, \underline{U}_a^{[o]}\right\}$, $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ are the fundamental symmetrical voltage phasor components, *i.e.* direct (or positive), inverse (or negative) and zero (or homopolar);
- $\left\{\underline{I}_a^{[d]}, \underline{I}_a^{[i]}, \underline{I}_a^{[o]}\right\}$, $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ are the fundamental symmetrical voltage phasor components;
- $U_{a,k}^{(h)}$ $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ and $k \in \{1, 2, 3\}$ are the phase voltage rms values of harmonic $h = 1, 2, \ldots$ or 0 for the dc component;
- $I_{a,k}^{(h)}$ $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ and $k \in \{1, 2, 3\}$ are the phase voltage rms values of harmonic $h = 1, 2, \ldots$ or 0 for the dc component;
- $\varphi_{a,k}^{(h)}$ $a \in \{\ell, \mathrm{L}, \mathrm{D}\}$ and $k \in \{1, 2, 3\}$ are the voltage–current phase shift values of harmonic $h = 1, 2, \ldots$;

The developed power theory admits from the very beginning the unanimously accepted definition for active power P and the Budeanu's definition for reactive power Q. Considering the Fourier series decomposition of voltage and current, if the *passive sign convention* is used for a mono-phase consumer, we have [12]

$$P = \frac{1}{T}\int_T u(t)i(t)\,\mathrm{d}t = U^{(0)}I^{(0)} + \sum_{h=1}^{\infty} U^{(h)}I^{(h)}\cos\varphi^{(h)}, \tag{2}$$

$$Q = \sum_{h=1}^{\infty} U^{(h)}I^{(h)}\sin\varphi^{(h)}, \tag{3}$$

where T is the fundamental period , $u(t)$ and $i(t)$ are the voltage and current corresponding to the single phase receptor. Note that in (2) the right-hand-side term $U^{(0)}I^{(0)}$ was added [15–18] as dc component to the original definition proposed by Professor Ţugulea, to account for the increasing rectifying effect of power electronics components, which are more and more present in industrial and domestic applications alike.

According with Tellegen's theorem [13], active power balance relationship for the network shown in Fig. 1 is written

$$P_{\mathrm{G}} = P_\ell + P_{\mathrm{L}} + P_{\mathrm{D}}, \tag{4}$$

where P_{G} is the active power generated by the voltage source and P_ℓ, P_{L} and P_{D} are the active powers received by the rest of the network components. Taking now into account the Fourier series decomposition we have for each of the right-hand side term of (4) the following relationship [1–5]

$$P_a = \sum_{k=1}^{3}\left(U_{a,k}^{(0)} I_{a,k}^{(0)} + \sum_{h=1}^{\infty} U_{a,k}^{(h)} I_{a,k}^{(h)} \cos\varphi_{a,k}^{(h)} \right) = \tag{5}$$
$$= P_a^{(1)} + \overbrace{P_a^{(0)} + \sum_{h=2}^{\infty} P_a^{(h)}}^{P_{a,\mathrm{r}}}, a \in \{\ell, \mathrm{L}, \mathrm{D}\},$$

allowing to define the *residual (distorting) active power* $P_{a,\mathrm{r}}$ for each network passive component. To be noted that in (5), for the same reasons mentioned above, the dc component $P_a^{(0)}$ was later included [15–18] additionally to the original definition. Furthermore, $P_a^{(1)}$ can be decomposed on symmetrical components (superscripts [*d*], [*i*] and [*o*] respectively) as [1–5]

$$P_a^{(1)} = \overbrace{P_a^{[d]}}^{P_{a,\mathrm{s}}} + \overbrace{P_a^{[i]} + P_a^{[o]}}^{P_{a,\mathrm{n}}}, a \in \{\ell, \mathrm{L}, \mathrm{D}\}, \tag{6}$$

in order to define the *symmetry* ($P_{a,\mathrm{s}}$) and *non-symmetr*y ($P_{a,\mathrm{n}}$) *active powers*. Note that the zero (homopolar) components are not present if the network is without neutral.

In a similar succession, we summarize the definitions for the reactive power [1–5, 13, 15–18]:

$$Q_{\mathrm{G}} = Q_\ell + Q_{\mathrm{L}} + Q_{\mathrm{D}}, \tag{7}$$

$$Q_a = \sum_{k=1}^{3}\sum_{h=1}^{\infty} U_{a,k}^{(h)} I_{a,k}^{(h)} \sin\varphi_{a,k}^{(h)} = \tag{8}$$
$$= Q_a^{(1)} + \overbrace{\sum_{h=2}^{\infty} Q_a^{(h)}}^{Q_{a,\mathrm{r}}}, a \in \{\ell, \mathrm{L}, \mathrm{D}\},$$

$$Q_a^{(1)} = \overbrace{Q_a^{[d]}}^{Q_{a,\mathrm{s}}} + \overbrace{Q_a^{[i]} + Q_a^{[o]}}^{Q_{a,\mathrm{n}}}, a \in \{\ell, \mathrm{L}, \mathrm{D}\}, \tag{9}$$

where Q_{G} is the reactive power generated by the voltage source and Q_ℓ, Q_{L} and Q_{D} are the reactive powers received by the rest of the network components. As shown in (8) and (9) the *residual (distorting)* ($Q_{a,\mathrm{r}}$), *symmetry* ($Q_{a,\mathrm{s}}$) and *non-symmetry* ($Q_{a,\mathrm{n}}$) *reactive powers* were defined.

In more detail, the active (P_{G}) and reactive powers delivered by the symmetrical generator (only on the positive sequence, obviously) can be obtained from the complex power by retaining the real and imaginary parts, respectively, as [12, 15–18]

$$\underline{S}_G = P_{\mathrm{G}} + \mathrm{j}Q_{\mathrm{G}} = P_{\mathrm{G,s}} + \mathrm{j}Q_{\mathrm{G,s}} = \tag{10}$$
$$= 3\underline{U}_{10}\left(\underline{I}_\ell^{[d]}\right)^* = 3U\left(\underline{I}_\ell^{[d]}\right)^*.$$

In a similar manner, one obtains the *symmetry* and *non-symmetry* powers through the fundamental complex powers corresponding to the three other components of the network [12, 15–18]:

$$\underline{S}_{a,\mathrm{s}}^{(1)} = P_{a,\mathrm{s}} + \mathrm{j}Q_{a,\mathrm{s}} = 3\underline{U}_a^{[d]}\left(\underline{I}_a^{[d]}\right)^* \tag{11}$$

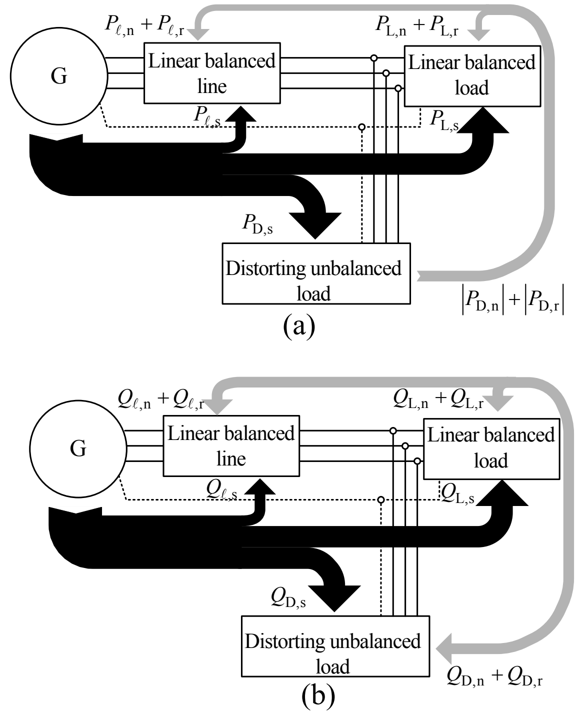

Fig. 2 – a) Sankey diagram of symmetry, non-symmetry and residual (distorting) active powers flow;
b) sankey diagram of symmetry, non-symmetry and residual (distorting) reactive powers flow.

$$\underline{S}_{a,\mathrm{n}}^{(1)} = P_{a,\mathrm{n}} + \mathrm{j}Q_{a,\mathrm{n}} = 3\left[\underline{U}_a^{[i]}\left(\underline{I}_a^{[i]}\right)^* + \underline{U}_a^{[o]}\left(\underline{I}_a^{[o]}\right)^*\right]. \tag{12}$$

Finally, by splitting (4) and (7) into several balance equations one may get [1–5, 15–18]:

$$\begin{cases} P_{\mathrm{G}} = P_{\ell,\mathrm{s}} + P_{\mathrm{L,s}} + P_{\mathrm{D,s}} \\ 0 = P_{\ell,\mathrm{n}} + P_{\mathrm{L,n}} + P_{\mathrm{D,n}} \\ 0 = P_{\ell,\mathrm{r}} + P_{\mathrm{L,r}} + P_{\mathrm{D,r}} \end{cases}, \tag{13}$$

$$\begin{cases} Q_{\mathrm{G}} = Q_{\ell,\mathrm{s}} + Q_{\mathrm{L,s}} + Q_{\mathrm{D,s}} \\ 0 = Q_{\ell,\mathrm{n}} + Q_{\mathrm{L,n}} + Q_{\mathrm{D,n}} \\ 0 = Q_{\ell,\mathrm{r}} + Q_{\mathrm{L,r}} + Q_{\mathrm{D,r}} \end{cases}, \tag{14}$$

which represent the essence of Professor Ţugulea's power theory. Since the voltage source is presumed as being purely sinusoidal and delivering power only on the positive (or direct) sequence, the left hand side of the active and reactive non-symmetry and residual (distorting) powers balance equations is zero. Since the passive sign convention was used, that implies that some right-hand side terms of these equations cannot simultaneously be positive, and therefore ones are negative, signifying that the respective power is in fact a generated one.

In what concerns the active power, it turns out that the component to "blame" is always the unbalanced load ($P_{\mathrm{D,n}} < 0$) whether it is linear or not. Similarly, for a supposed distorting load (even balanced), one gets $P_{\mathrm{D,r}} < 0$. Interestingly, the characteristic of being unbalanced or distorting makes the considered load to act in a similar way: to inject unwanted power throughout the grid. For the sake of generality, if the load cumulates both shortcomings the phenomenon is described by the balance equalities $|P_{\mathrm{D,n}}| = P_{\ell,\mathrm{n}} + P_{\mathrm{L,n}}$ and $|P_{\mathrm{D,r}}| = P_{\ell,\mathrm{r}} + P_{\mathrm{L,r}}$ and illustrated in Fig. 2a.

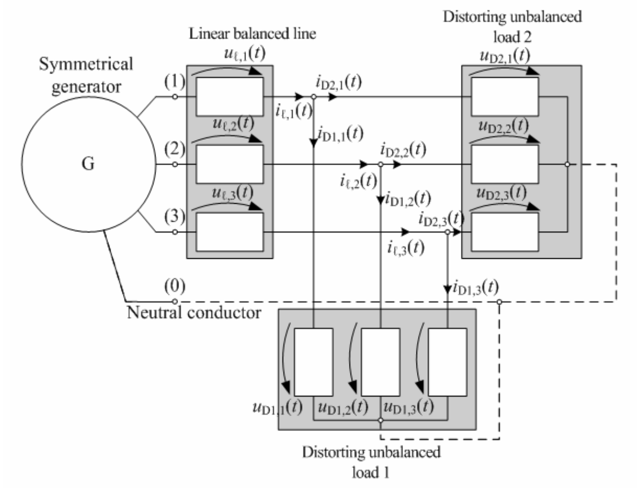

Fig. 3 – Simplified model of a three-phase network (with / without neutral) comprising a symmetrical generator and two distorting (nonlinear) unbalanced loads.

These two relationships do not have a similar form for the reactive power as shown in Fig. 2b by a bidirectional reactive power flow, as proved numerically in [15–18]. As it can be seen in Fig. 2a, the "legitimate" linear line and load are overcharged with active power injected by the distorting nonlinear load.

3. RECENT ADVANCES

In an effort to generalize the useful observations presented and discussed in the previous section, some more complex structures (with neutral and without, respectively) have been assessed in [17, 18]. For both network models two different distorting unbalanced loads were considered, as shown in Fig. 3.

Still using the passive sign convention for each mono-phase receptor component of the three-phase elements, and the previous section voltage and current notations, the indexes will become $a \in \{\ell, \mathrm{D1}, \mathrm{D2}\}$, corresponding to the linear balanced line and the two distorting unbalanced loads, respectively.

Four different simplified models (M1 – M4) were considered for which the D1 and D2 consumers have different structures (nonlinear inductors, thyristors, diodes in various combinations) in a three-phase network with neutral.

The voltage and current distribution was computed numerically and then used to obtain the powers defined in Section 2, *e.g.* using the efficient methods presented in [19, 20]. By ignoring the numerical value itself and only interpreting its sign (in the passive sign convention) the following active and reactive power transfer direction was summarized in Tables 1 and 2, respectively, being reproduced from [17].

Table 1

Non-symmetry and residual (distortion) active power transfer direction (passive sign convention) in circuits with neutral

	Non-symmetry power (P_n)		Residual (distortion) power (P_r)	
Model	D1	D2	D1	D2
M1	**Generated**	*Received*	**Generated**	*Generated*
M2	**Generated**	Generated	**Received**	Generated
M3	Generated	***Received***	Generated	***Generated***
M4	**Received**	Generated	**Received**	Generated

Table 2

Non-symmetry and residual (distortion) reactive power transfer direction (passive sign convention) in circuits with neutral

	Non-symmetry power (Q_n)		Residual (distortion) power (Q_r)	
Model	D1	D2	D1	D2
M1	**Generated**	***Received***	**Generated**	***Generated***
M2	**Received**	Received	**Received**	Received
M3	Generated	***Generated***	Generated	***Received***
M4	Generated	Generated	Generated	Generated

A similar problem was investigated for test models (M5 – M8) in circuits without neutral and some other D3 and D4 load configurations. The results were organized in Tables 3 and 4, being reproduced from [18].

Table 3

Non-symmetry and residual (distortion) active power transfer direction (passive sign convention) in circuits without neutral

	Non-symmetry power (P_n)		Residual (distortion) power (P_r)	
Model	D3	D4	D3	D4
M5	**Generated**	Generated	**Generated**	Generated
M6	**Generated**	Generated	**Received**	Generated
M7	Generated	***Received***	Received	***Generated***
M8	**Received**	Generated	**Received**	Generated

Table 4

Non-symmetry and residual (distortion) reactive power transfer direction (passive sign convention) in circuits without neutral

	Non-symmetry power (Q_n)		Residual (distortion) power (Q_r)	
Model	D3	D4	D3	D4
M5	**Generated**	***Received***	**Generated**	***Generated***
M6	Generated	Generated	Generated	Generated
M7	Generated	Generated	Generated	Generated
M8	**Generated**	***Received***	**Received**	***Received***

From the perspective of no matter which distorting unbalanced load (D1 or D2), Tables 1 – 4 prove the existence of all the possible combination of generated and received non-symmetry and residual (distortion) active and reactive powers at a terminals of such a load. At the same time they prove the existence of any possible pair of power exchange for the pairs (D1, D2) and (D3, D4), respectively.

To conclude, when multiple distorting unbalanced loads are present in a network, the non-symmetry and residual (distorting) active powers do not exhibit the same unidirectional flow as for the network shown in Fig. 1a and used in the original Ţugulea theory to illustrate the harmful effects inflicted by such type of circuit elements.

4. FUTURE PERSPECTIVES

Firstly, as suggested by the conclusion drawn at the end of the previous section, the existence of more than one distorting unbalanced load in the network significantly complicates the task of identifying the consumer which originates the harmful effects throughout the grid. There is a sense that some objective (mathematical) criteria concerning the distorting unbalanced loads must be found to the extent that allows a clear prediction of the transfer direction of non-symmetry and residual (distorting) active powers and also, if it would be possible, for the non-symmetry and residual (distorting) reactive powers.

Secondly, apart from the theoretical study of the subject, but still in connection with it, there is the practical problem of measuring (in real time preferably) the non-symmetry and residual (distorting) active and reactive powers at the connection point of some industrial or domestic three-phase consumer, in order to accurately establish the real energy cost to be billed.

5. CONCLUSIONS

Professor Ţugulea's visionary power theory founded in mid 1980s can provide nowadays a theoretical foundation for investigating and measuring active and reactive powers, in the context of the ever increasing distorting devices and distorting equipment connected to the power grid. This theory not only remains actual, but has the potential of being generalized for an indefinite number of distorting consumers, fact that would represent an important step forward in modeling and understanding modern power grids characteristics and operation.

The present paper was elaborated aiming to bring in the spotlight, for the present day academic community, an important Romanian electrical engineering theory, which represents at the same time a major scientific legacy contribution of Professor Andrei Ţugulea, Member of the Romanian Academy.

Received on March 10, 2018

REFERENCES

1. A. Ţugulea, *Consideraţii privind efectele energetice ale regimului deformant*, Energetica, **XXXIV**, *1*, pp. 27–31 (1986).
2. A. Ţugulea, *Consideraţii privind efectele energetice în regimurile armonice nesimetrice ale reţelelor trifazate*, Energetica, **XXXIV**, *3*, pp. 121–130 (1986).
3. A. Ţugulea, Carmen Golovanov, *Efectele energetice ale regimurilor nesimetrice şi deformante ale sistemelor electroenergetice. Posibilităţi de măsurare*, ENERG, *3*, pp. 130–159 (1987).
4. A. Ţugulea, *Power flows under non-sinusoidal and non-symmetric periodic and almost periodic steady-states of electrical power system*, Proc. of 6th Int. Conf. On Harmonics in Power Systems (ICHPS VI), Bologna , Italy, pp. 388–395 (1994).
5. A. Ţugulea, *Criteria for the definition of the electric power quality and its measurement systems*, European Transactions on Electrical Power, **6**, *5*, pp 357–363 (1996).
6. M.E. Balci, M.H. Hocaoglu, *A power resolution for nonsinusoidal and unbalanced systems – Part I: Literature overview and motivation*, 7th Int. Conf. on Electrical and Electronics Engineering (ELECO), pp. I-167 – I-172 (2011).
7. H. Abniki, A.A.M. Birjandi, S.N. Jahromi, *Best mutual demand response and load profile in smart grids*, Roum. Sci. Techn. – Électrotechn. et Énerg., **58**, *4*, pp. 367–374 (2013).
8. M. Büyük, M. İnci, M. Tümay, *Performance comparison of voltage sag/swell detection methods implemented in custom power devices*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **62**, 2, pp. 129–133 (2017).
9. M.S.K. Niya, A. Kargar, S.Y. Derakhshandeh, *Effects of angle droop and controller type in hybrid microgrid with load uncertainty and nonlinearity*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **62**, *3*, pp. 233–239 (2017).
10. S. Jamali, H. Borhani-Bahabadi, *New recloser characteristic to improve fuse saving in distribution networks with distributed generation*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **62**, *3*, pp. 240–245 (2017).
11. R. Dehini, R. Berbaoui, *L'identification des courants harmoniques face à la perturbation de la tension (The harmonics currents identification faces to the voltage disturbance)*, Rev. Roum. Sci. Techn.– Électrotechn. et Énerg., **62**, *4*, pp. 346–351 (2017).
12. A. Moraru, *Bazele electrotehnicii – teoria circuitelor electrice*, Edit. Matrix Rom, 2002.
13. B.D.H. Tellegen, *A General Network Theorem, with Applications*, Philips Res. Rep., **7**, pp. 259–269 (1952).
14. C.I. Budeanu, *Puissances réactives et fictives*, Institut Roumain de l'Énergie, **2** (1927).
15. I.V. Nemoianu, R. M. Ciuceanu, *Non-symmetry and residual active and reactive powers flow in non-linear three-phase unbalanced circuits*, Roum. Sci. Techn. – Électrotechn. et Énerg., **60**, *2*, pp. 227–237 (2015).
16. I.V. Nemoianu, R.M. Ciuceanu, *Characterization of non-linear three-phase unbalanced circuits powers flow supplied with symmetrical voltages*, Roum. Sci. Techn. – Électrotechn. et Énerg., **60**, *3*, pp. 355 – 365 (2015).
17. I.V. Nemoianu, R.M. Ciuceanu, *Aspects of active and reactive powers conservation in three-phase circuits with zero impedance neutral and two nonlinear unbalanced loads*, Roum. Sci. Techn. – Électrotechn. et Énerg., **61**, *4*, pp. 349–354 (2016).
18. I.V. Nemoianu, M. Maricaru, R.M. Ciuceanu, *Active and Reactive Power Flow in Distorting Three-Phase Unbalanced Circuits Without Neutral*, International Symposium on Fundamentals of Electrical Engineering (ISFEE), "Politehnica" University of Bucharest, Romania, June 30–July 2016.
19. I. F. Hănţilă, M. Maricaru, F. Constantinescu. R.M. Ciuceanu, *A new method for time domain computation of steady state in nonlinear circuits*, 2011 IEEE International Conference on Microwaves, Communication, Antennas and Electronics Systems (COMCAS), pp.1–6, Tel-Aviv, Israel, 7–9 nov. 2011.
20. I. F. Hănţilă, M. Maricaru, R.M. Ciuceanu, L. Corlan, *Harmonic analysis of circuits with nonlinear resistive elements*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **57**, *4*, pp. 333–340 (2012).