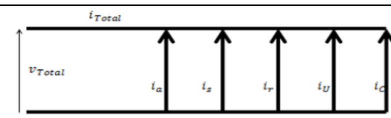
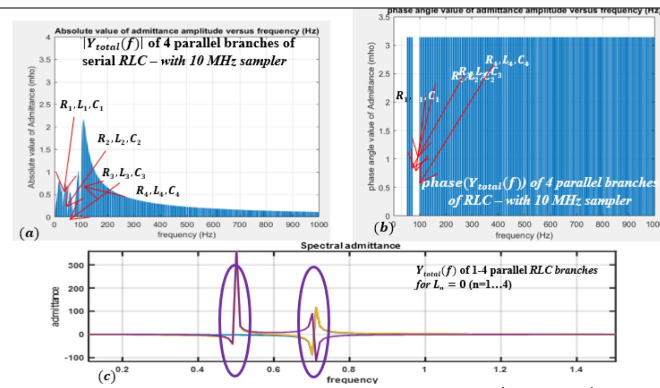
No	Mathematical formulation	Physical interpretation
	Paper 1 theorems	
	Anomaly detection enhancement theorems	
1	$S_{\omega}^{I_R} \triangleq {}^{1}\!/_{I_R}\left({}^{\partial I_R}\!/_{\partial \omega}\right) = {}^{1}\!/_{I_R}\left({}^{\partial I_{R,Scattered}}\!/_{\partial \omega}\right), {}^{\partial I_{R,fixed}}\!/_{\partial \omega} = 0$	**Scattered currents sensitivity theorem**: The scattered current may be significantly smaller than total active/reactive current and yet the spectral change information is located there, due to fact that sensitivity measure $S_{\omega}^{I_R}$ of the system's change is there.
2	$i_R = v / R, i_C(s) = sCv, i_L(s) = v / (sL)$ $s = \sigma + j\omega : \partial i_R / \partial s = 0,$ $\partial i_C / \partial s = Cv, \partial i_L / \partial s = v / (-s^2 L)$	**Reactive scatter current sensitivity:** The reactive→ scatter current signature is more likely to catch changes than total current or active current: Changes over reactive components. Resistive spectral relation is fixed, reactive is pole/zero dependent.
3	$i_C(j\omega) = j(\omega C v) = e^{j\pi/2}(\omega C v), i_L(j\omega) =$ $= e^{-j\pi/2}(v / (\omega L))$	**Reactive current sensitivity:** phase may contribute to anomaly detection not less than amplitude signature, at reactive components and mixed active+ reactive components
	Grid/machinery deciphering theorems	 **CPC parallel currents**
4	$Y_{Total}(Z) = Y_{active}(Z) + Y_{Scattered}(Z) + Y_{Reactive}(Z) +$ $+ Y_{Customer}(Z) + Y_{Unbalanced}(Z) = \sum_m I_m(Z) / V(Z) \triangleq \sum_m Y_m$	**Admittance function separability theorem:** as observed from above schematics –admittance transfer function may be modeled as composed of several admittance physical components. Published paper.**שגיאה! מקור ההפניה לא נמצא.**
5	$i_{m,total} = \sum_n i_{n,m}$ where: $i_{m,total}$- total current physical component of type m $index \in \{CPC, E-\ CPC\ current\ types\}$ and n branch index $i_{n,m}$- current at branch n of CPC type m parallel	**Currents physical components separability theorem:** Looking at an electric scheme with n parallel branches, the following current relation is maintained at CPC.
6	$Y_{m,total} = \sum_n Y_{n,m}$ where: $Y_{m,total}$- total current physical component 'admittance' of type $m \in \{CPC\ current\ types\}$ $Y_{n,m}$- current physical component 'admittance' at branch n of CPC type m including this paper enhanced CPC	***"RL* serial circuit" reactive admittance theorem:** Following CPC relations then admittance relations are maintained
7	$Y_{total \to reactive \to scattered} = \mathrm{Im}\{Y_{total \to active}\} =$ $= \sum_m -\omega L_m / (R_m^2 + \omega^2 L_m^2)$ Reason that is written is because it may mistakenly be considered that following is correct: $Y_{total \to reactive} = \sum_m 1/(j\omega L_m)$	***"RL* serial circuit" active admittance theorem:** for a linear load that includes only resistors and inductors the total→ reactive→ scatter admittance, equals the sum of all parallel inductors, admittances

8	$Y_{total \to active \to scattered} = \mathrm{Re}\{Y_{total \to active}\} =$ $= \sum_m R_m / (R_m^2 + \omega^2 L_m^2)$ Reason that is written is because it may mistakenly be considered that following is correct: $Y_{total \to active} = \sum_m 1/R_m$	**"*RLC* serial circuit" admittance theorem:** For linear loads with resistive elements at the parallel branches, the total→ active admittance, equals to the sum of real segments of admittances (not of the resistors only) and is not sum only of resistors.
9	(17) $Y_{total}(s) =$ $= \sum_m [R_m - j(\omega L_m - 1/\omega C_m)] / [R_m{}^2 + (\omega L_m - 1/\omega C_m)^2]$ The bellow does not show at paper 1. Generalization: $Y_{total \to reactive,m}(\omega) = \mathrm{Im}\{Y_{total,m}\}$ $Y_{total \to active,m}(\omega) = \mathrm{Re}\{Y_{total,m}\}$ $Y_{total \to reactive}(\omega) = \sum_m \mathrm{Im}\{Y_{total,m}\}, Y_{total \to active}(\omega) = \sum_m \mathrm{Re}\{Y_{total,m}\}$	**RLC serial total admittance separability:** 1) for linear loads with mixture of inductors and capacitors at the load parallel branches, the total admittance, that is computable, equals the sum of all parallel active admittances separately+ reactive admittances separately. Example for serial RLC. The bellow does not show at paper 1 2) generalization: For linear loads with mixture of inductors and capacitors at the load parallel branches, the total→ reactive admittance, that is computable, equals the sum of all parallel imaginary segments of branch admittances
		 Fig. 5: Admittance function simulated results (a) $\|Y_{total}(f)\|$ (b) phase$(Y_{total}(f))$- (a)+(b) – 4 parallel branches of serial *RLC* (c) $\sum_n -\omega C_n/(1 + C_n R_n \omega^2)$ for n=1,…,4 various $R_n, C_n (L_n = 0)$ values
10-a	(18) $G_e = P/\|u\|^2 = \sum_{n \in N_D \oplus N_C} G_n u_n^2 / \sum_{n \in N_D} u_n^2$ $where: G_n = R_m / \left[R_m^2 + (\omega_n L_m - 1/(\omega_n C_n))^2 \right]$ $B_e = Q/\|u\|^2 = \sum_{n \in N_D \oplus N_C} B_n u_n^2 / \sum_{n \in N_D} u_n^2$ $where: B_n = -(\omega_n L_m - 1/(\omega_n C_n)) / \left[R_m^2 + (\omega_n L_m - 1/(\omega_n C_n))^2 \right]$ Where: *n*- harmonic index *m* – branch index N_D – set of harmonic indices that are at distribution current. N_C- set of harmonic indices that are at customer current	**Admittance correlation to CPC.** Equating between transfer measured-computed admittance function for linear load, the total (customer+ distribution)→ reactive→ fixed current is close to zero. Although the reactive component of for example parallel branches of serial RLC looks spectral, at CPC spectrally constant component is extracted according to equation herein. This theorem relates to important issue: The components based active/reactive admittance transfer functions from eq. are based on 'total' active and reactive currents.

10-b	$i_{reactive,total} = i_{CPC,reactive,distribution} + i_{CPC,reactive,customer}$ $i_{active,total} = \left(i_{CPC,active\to fixed} + i_{CPC,active\to scattered}\right)_{distribution} + \left(-"-\right)_{customer}$	**Relation between CPC and classical theory:** Eq. is important because “measured-computed admittance” is according to eq. CPC+Z-transform whereas the proposed electric scheme for comparison is described by eq.
11		**Active spectral component:** for linear load, the total (customer+ distribution)→ active→ scatter current is not zero. The total→ reactive→ fixed is not zero. It is according to eq.. Reason theorem is brought is not to suppose by mistake that $Y_{total,real} = \sum_n 1/R_n$ simply because $i_{total,real} = \sum_n i_{n,real}$. The active component of each branch is containing spectral reactive components. The bellow does not show at paper 1: Same, theorem is brought so not to suppose by mistake that $Y_{total,imag} = \sum_n j\omega C_n - j\,1/\omega L_n$ simply because $i_{total,imag} = \sum_n i_{n,imag}$.
12	$if\ rule-is-correct\quad for:\{all\ n\in N_D\}\quad then$ $rule-is-correct-for:\{all\quad n\in N_C\}\quad \&\&\{n\in N_C+N_D\}$	**method enlargement to HGL:** theorems 3)-5) are correct also for Harmonic Generating Load (HGL). Practically there might be changes. Mathematically formulating it referring to paper.**שגיאה! מקור ההפניה לא נמצא**.
13	$\left(1/Y_m\right)\partial/\partial\omega\left(i_m(\omega)/v_m(\omega)\right) =$ $= \left[i'_m(\omega)/i_m(\omega) - v'_m(\omega)/v_m(\omega)\right]$ Where: m index ∈ $\{CPC, enhanced\ CPC\ current\ types\}$	**anomaly enhancement by admittance.** Admittance physical component improves the anomaly detection. Proof: the spectral sensitivity is a measure of ‘the change’ signature since it’s based on ‘many frequencies change-detection’. Eq. is to be correctly interpreted ‘not’ as admittance dependency stand-alone on current i'/i and over voltage v'/v. Correct interpretation is ‘admittance is independent of voltage amplitude’. Since current contains dependency over voltage through $i = Yv$ – the voltage dependent component is approx. subtracted – leaving only/mainly the ‘non-voltage dependent’.
14	$Y_{customer\to reactive\to scattered}(\omega_i) = Y_{inductive}(\omega_i) + Y_{capacitve}(\omega_i)$	separability of inductive and capacitive admittances. Inductive and capacitive components may be separated from the total (customer+ distribution)→ reactive→ scatter admittance. Proof: using at least two harmonics $i = 1,2$
	Theorems outside paper 1	
15	All of the above theorems 1-13 are correct both for CPC 5 components,& E-CPC 22 components.	For E-CPC 6 scatter currents, and for CPC- 1 scatter current
16	All of the above theorems 1-14 are correct for Laplace transform and for Z-transform	
17	1)For <u>reactive</u> components – entire reactive current should be taken, and not only customer→ reactive current. 2)For load current – <u>entire current</u> should be taken and not only customer current	An especially important theorem that is derived from comprehension of definition of customer current as defined at CPC Verified experimentally
18	Signature Conjecture: it is speculated that originally matching zero-poles are close/ overlapping for linear loads, deviating apart for non-linear loads	Demonstrated empirically at published paper, and to be attempted proven theoretically at thesis. Recently an interesting related paper published.

No	Mathematical formulation	Physical interpretation
	Paper 2 theorems	**Load disaggregation**
1	**Interpretation:** “None” represents not a “vacuum” of devices, but “all the rest”. Outside the “kitchen” there are devices electrically resembling the kitchen devices. PCA being an orthogonal variables representation, when the “None” clusters have a large boundary or appear to be embedded with the device cluster – then confusion scoring shall be higher.	**PCA correlation of “None” object instance to device.** **Theorem:** the closest the “None” is to a device cluster, the higher “confusion” scoring between the “None” and the device.
2		**“None” confusion with devices.** The “None” has larger confusion scoring with devices than a device with another device. Explanation: since “None” is a collection of devices outside kitchen then it may contain signatures of devices that electrically resemble a kitchen device.
3	This is a weaker more general version of theorem #1.	**Correlation between distance at PCA space and confusion.** Devices that are near each other at PCA space, the “confusion” scoring shall be higher between devices.
4		