Ph.D. 2nd year presentation

on

Power Stages and Control for Wireless Power Transfer Systems (WPTSs)

Presented by

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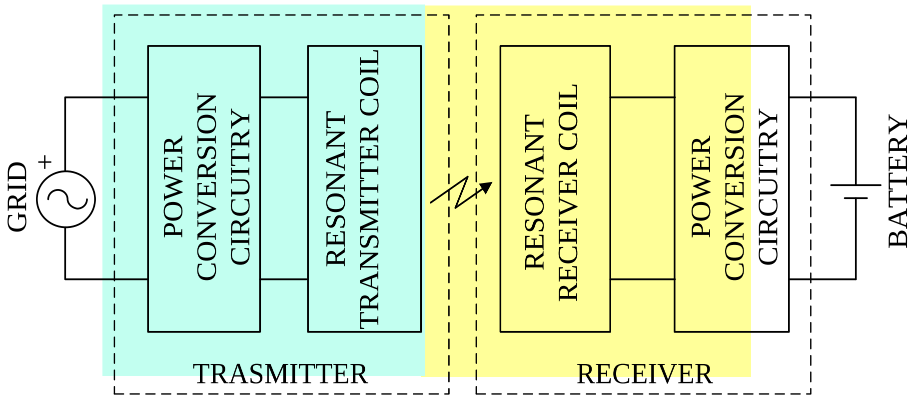
PRESENTATION OUTLINE

1. Wireless Battery Charging (WBC) Scheme
2. Resonant WBC
3. Figures Of Merits (FOMs)
4. FOMS calculations
5. Analysis and comparison of two WBC arrangements
6. Dynamic model of system
7. Conclusions and future work
8. Personal training plan
9. References

1. WIRELESS BATTERY CHARGING SCHEME

Resonant WBC schematic

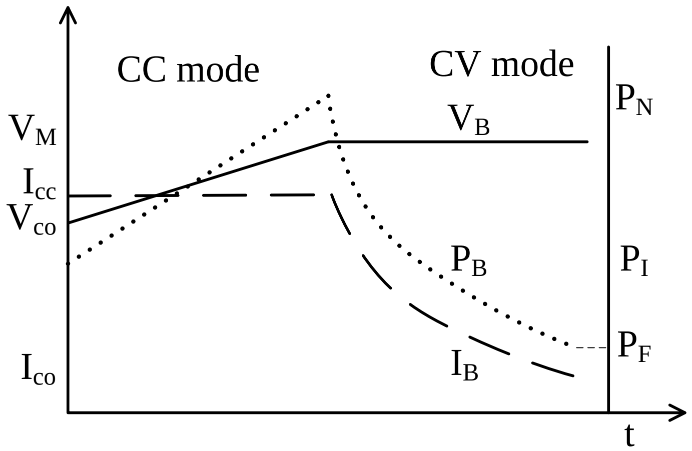


Transmitter Stage	
Grid voltage	230 V_{rms}
Power conversion circuitry	Grid rectifier and high frequency voltage inverter
Resonant transmitter coil	Series-series (SS) or series-parallel (SP) LC resonance

Receiver Stage	
Resonant receiver coil	Series-series (SS) or series-parallel (SP) LC resonance
Power conversion circuitry	Diode rectifier and chopper

BATTERY CHARGING PROFILE

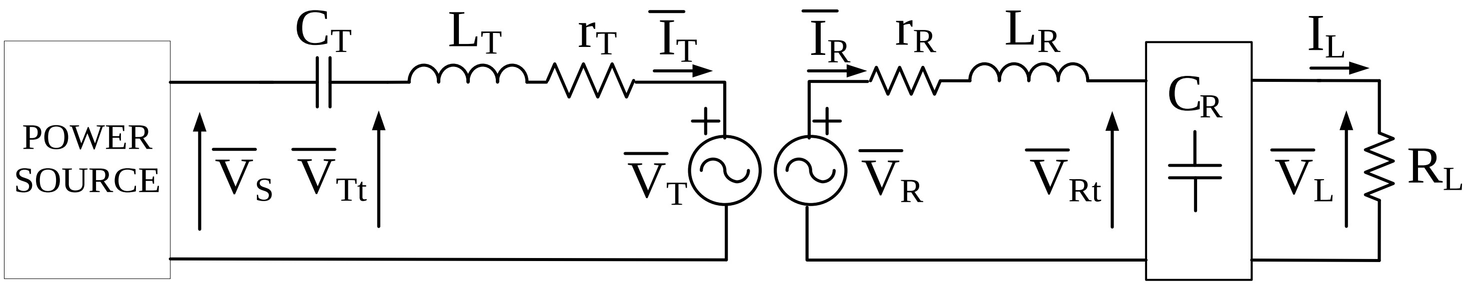
Battery charging profiles of voltage (solid line), current (dashed line), and power (dotted line).



Symbol	Data
I_B , V_B	Battery current and voltage
I_{CC} , I_{co}	I_B in CC mode and at cutoff
V_M , V_{co}	V_B in CV mode and at cutoff
P_B	Power absorbed by battery
P_I , P_F	P_B at the beginning and completion of battery charging
P_N	Nominal battery power defined as $V_M I_{CC}$

2. RESONANT WBC

SS and SP are commonly used because of its capability to manage a receiver short-circuit by adjusting the supply of the transmitter. Furthermore it does not need the insertion of an inductor at the output of the power source, when the latter one behaves as a voltage supply



WBC with series LC resonant transmitter coil

$$\begin{cases} \bar{V}_T = j\omega M \bar{I}_R \\ \bar{V}_R = -j\omega M \bar{I}_T \end{cases}$$

3. FIGURES OF MERIT

WBC performance is investigated in terms of efficiency η, power sizing factor of the power source (PSPSF) and power sizing factor of the coil coupling set (CCPSF). They are defined as

$$\eta \triangleq \frac{P_B}{P_S}$$

$$PSPSF \triangleq \frac{A_S}{P_N}$$

$$CCPSF \triangleq \frac{A_T + A_R}{P_N}$$

P_S	Active power delivered by the power source
A_S	Power source power sizing
A_T	Transmitter coil power sizing
A_R	Receiver coil power sizing

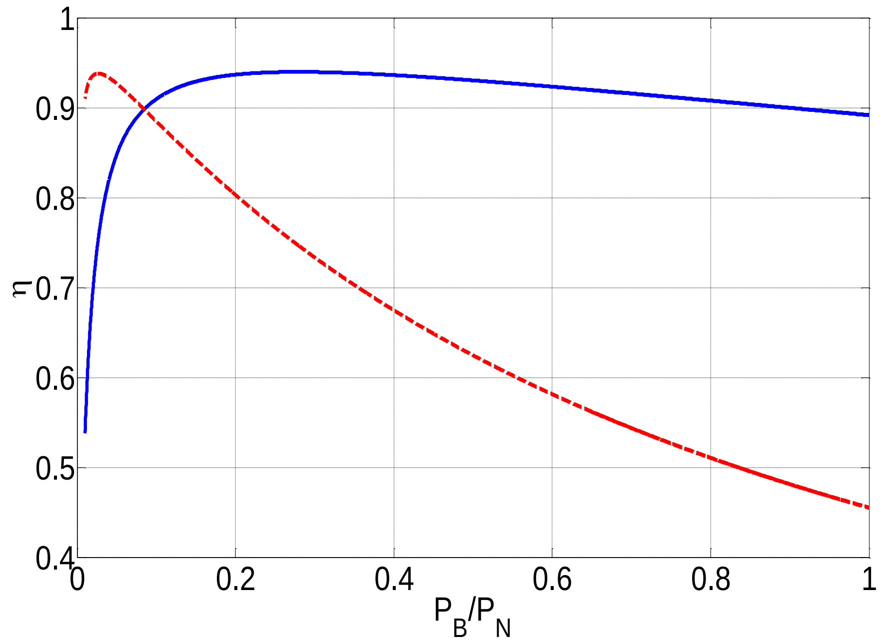
$$A_S = max(V_S)max(I_T)$$

$$A_T = max(V_{Tt})max(I_T)$$

$$A_R = max(V_{Rt})max(I_R)$$

- PSPSF and CCPSF are indexes of both cost and volume of WBC with respect to the nominal charging power of the battery.

EFFICIENCY COMPARISON



Red dashed line for SP and blue solid line for SS topology

- Efficiency of the SP topology exceeds the SS one only when P_B is lower than 0.083 P_N, which is below the minimum power of 0.1 P_N required to charge EV.
- Maximum efficiency is nearly the same for both the topologies and is of about 94%; the power in correspondence of the maximum efficiency is 0.28 P_N for the SS topology and 0.026 P_N for the SP one.

4. FOMS CALCULATIONS

Besides PSPSF and CCPSF, the power sizing factor of the transmitter coil (TCPSF) and the power sizing factor of the receiver coil (RCPSF) are calculated, and defined respectively as

$$TCPSF \triangleq \frac{A_T}{P_N} \qquad RCPSF \triangleq \frac{A_R}{P_N}$$

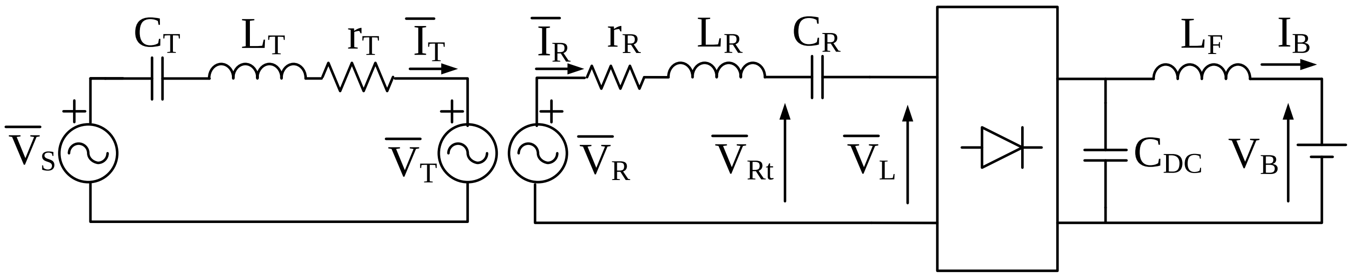
POWER SIZING FACTORS OF SS AND SP TOPOLOGIES		
FOM	SS	SP
PSPSF	1	9.33
CCPSF	15.6	135
TCPSF	1.48	134
RCPSF	14.1	1

Values of TCPSF and RCPSF point out that

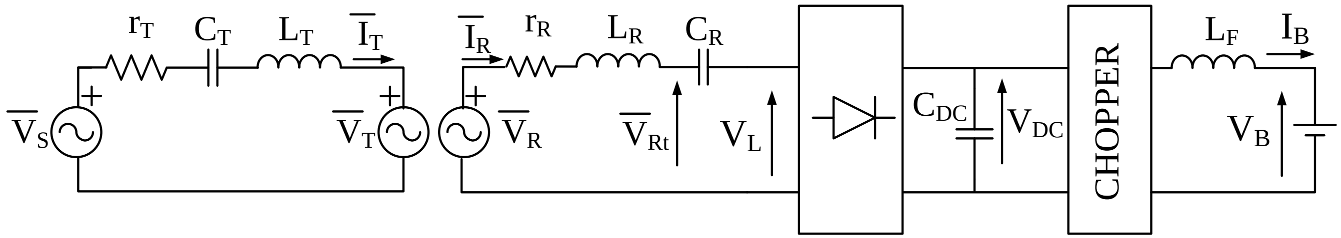
- With the SS topology, RCPSF is about 10 times higher than TCPSF so that it contributes to CCPSF in a dominant way. The opposite occurs for the SP topology, where CCPSF is due nearly entirely to TCPSF

5. ANALYSIS AND COMPARISON OF TWO WBC ARRANGEMENTS

The most popular solutions for a WBC receiver charge the battery either in a straight-forward manner through a diode rectifier or through a chopper in cascade to the diode rectifier, and controls the voltage of the power source in the transmitter to adjust the power absorbed by the battery.

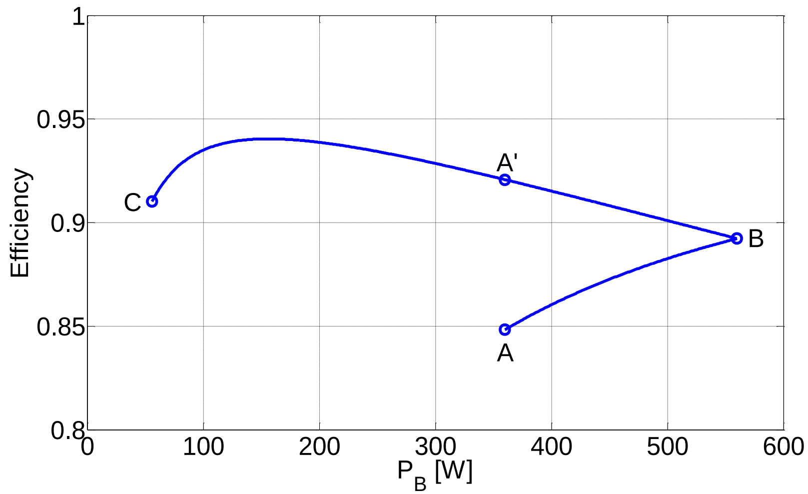


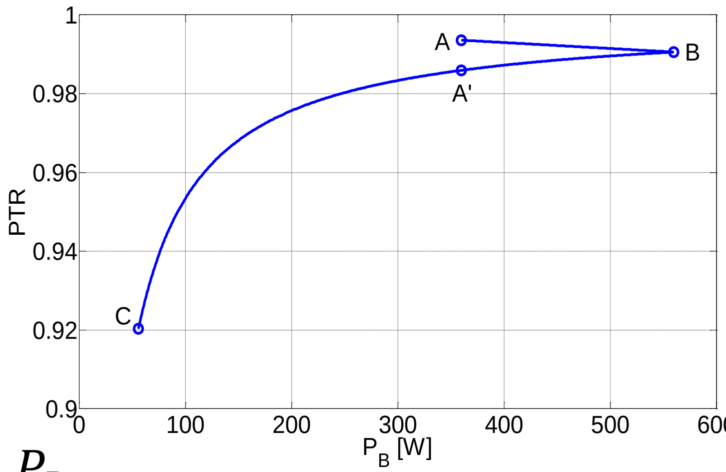
WBC arrangement without chopper i.e. (arrangement #1)



WBC arrangement with chopper i.e. (arrangement #2)

ARRANGEMENT COMPARISON



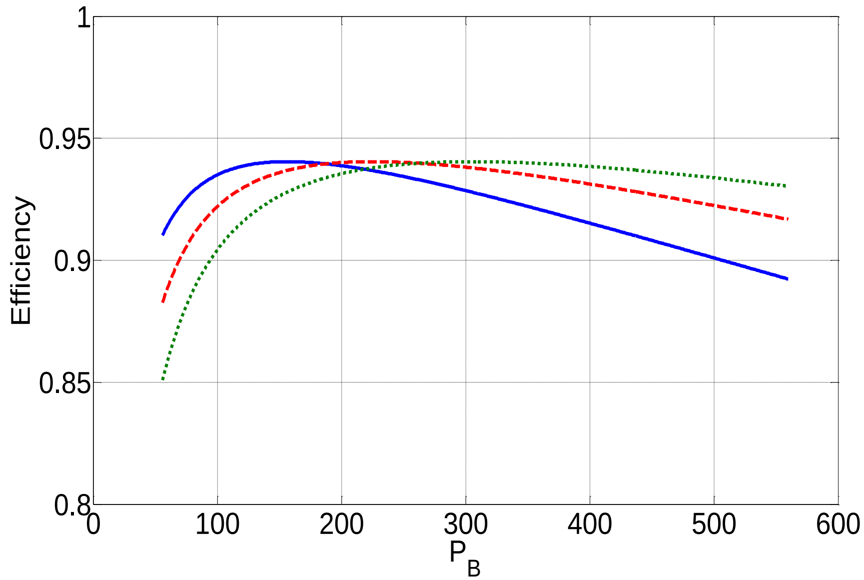


$$PTR \triangleq \frac{P_R}{P_S}$$

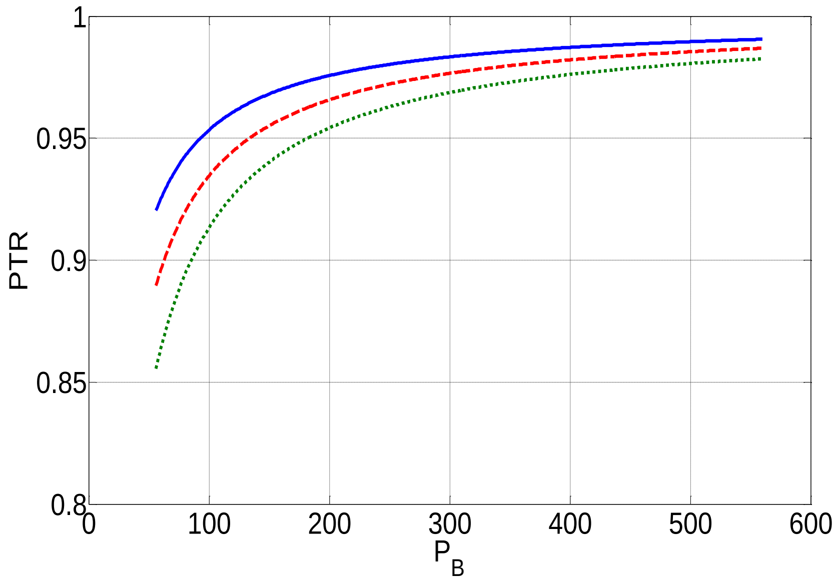
The curves of efficiency and PTR are ABC for arrangement #1 and A'BC for arrangement #2.

- Arrangement #1
  CC mode starts from point A and moves to B from there CV mode starts and continues till point C.
- Arrangement #2
  CC mode starts from point A' and moves to B while CV mode starts from point B continues to C.

V_{DC} EFFECT ON FOMs



Efficiency for WBC arrangement #2 with $V_{DC}=V_M$ (blue solid line), $V_{DC}=1.2\ V_M$ (dashed red line) and $V_{DC}=1.4\ V_M$ (green dotted line).



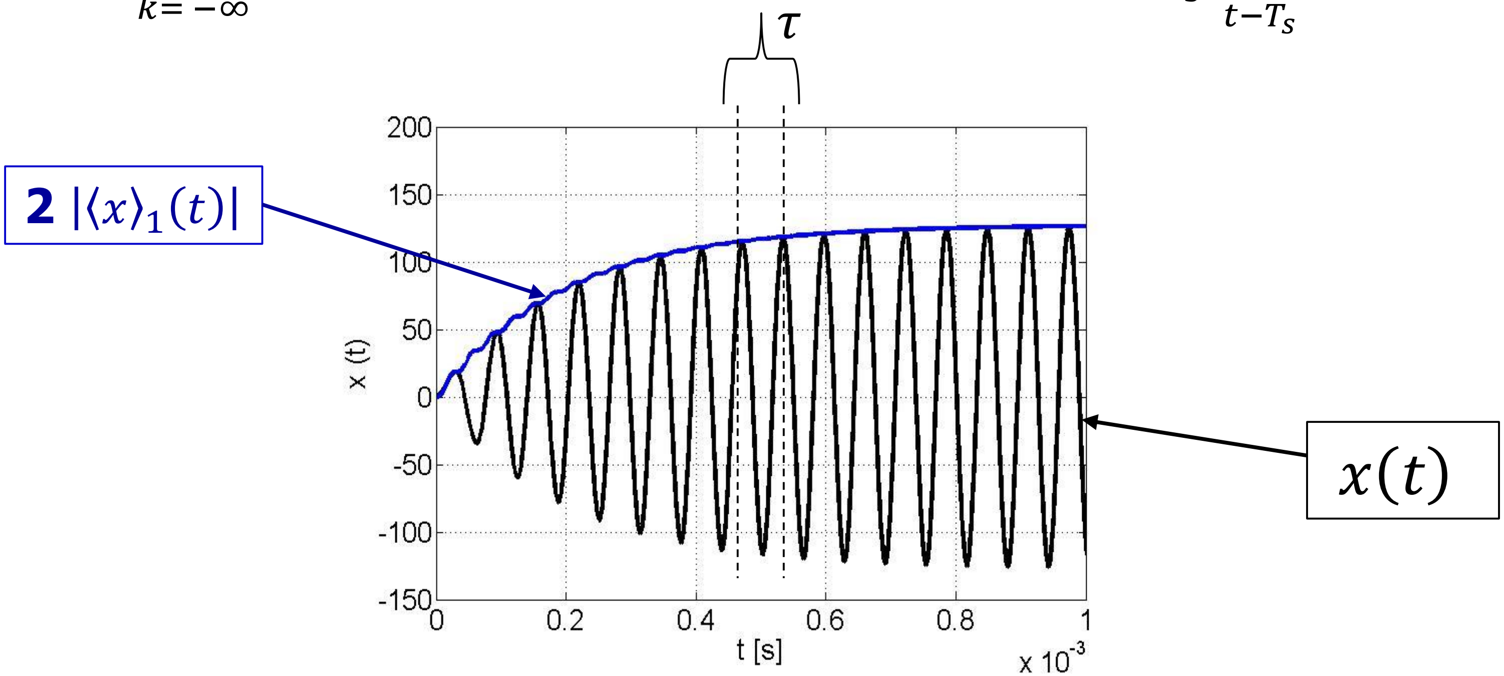
PTR for WBC arrangement #2 with $V_{DC}=V_M$ (blue solid line), $V_{DC}=1.2\ V_M$ (dashed red line) and $V_{DC}=1.4\ V_M$ (green dotted line).

The PSSF values calculated for the three values of V_{DC} by accounting for the parasitic resistances are: 1.12 for $V_{DC}=V_M$, 1.09 for $V_{DC}=1.2\,V_M$ and 1.07 for $V_{DC}=1.4\,V_M$, highlighting a small decrease of PSSF at the higher values of V_{DC}

6. DYNAMIC MODEL OF SYSTEM

- The dynamic model of a WPTS that considers the envelope of the alternating signal. Generalized state space averaging (GSSA) and Laplace phasor transform (LPT) technique are generally used for this.
- GSSA method is based on the fact that any waveform can be approximated in the form of Fourier series representation for any finite interval using its first coefficient for state space mode.

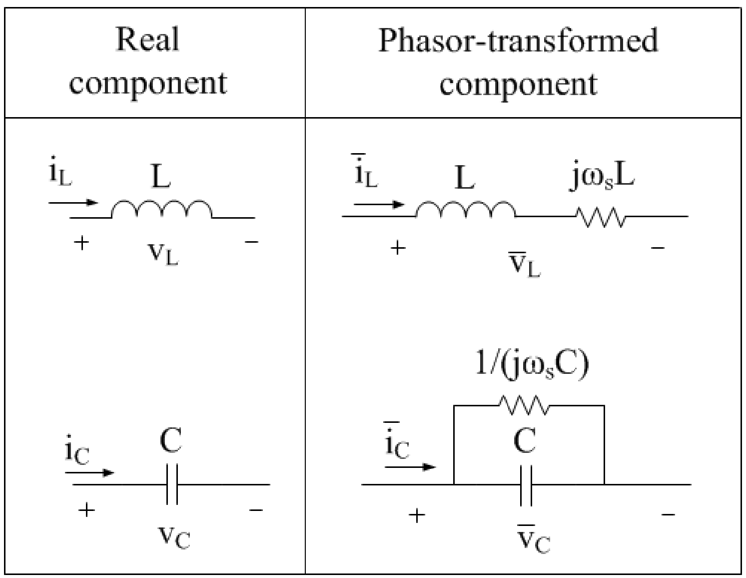
$$x(\tau) = \sum_{k=-\infty}^{k=+\infty} \langle x \rangle_k(t)\, e^{jk\omega_s\tau}, \quad \tau \in [t - T_s, t] \quad \langle x \rangle_k(t) = \frac{1}{T_s} \int_{t-T_s}^{t} x(\tau)\ e^{-jk\omega_s\tau}\, d\tau$$

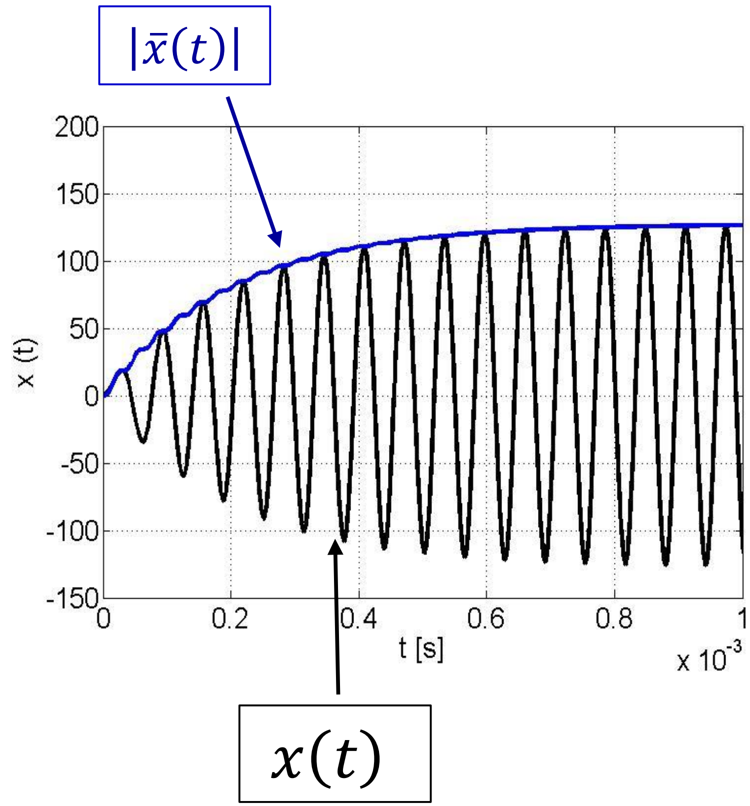


DYNAMIC MODEL OF SYSTEM Cont’d

- Laplace phasor transform (LPT) technique basically converts rotatory ac domain circuit into stationary domain circuit

$$x(t) = Re\{\bar{x}(t)e^{j\omega t}\}$$





5. CONCLUSIONS AND FUTURE WORK

- Comparative study of different resonant topology is done and most suitable topology for WBC is selected.
- Two different WBC arrangements are compared on the basis of FOMs.
- GSSA and LPT are studied in order to get the dynamic model of system.
- The activities planned for the 3rd year will be focused on the study and analysis of a high power WBC system to reduce the charging time and extend the range of EVs using computer assisted simulation.
- I have planned to conduct some experiments on a prototype setup to test some performance for the study-case of WBC system.

6. PERSONAL TRAINING PLAN

EDUCATIONAL ACTIVITIES ACTIVATED BY THE STMS PHD COURSE							
Course/Seminar (Period/Date)	Teacher	Duration (hours) of course / seminar	Attainable ECTS credits	Frequency (YES/NO)	Exam (YES/NO and type)*	Date of exam**	Attained ECTS credits
Fundamentals of measurements and PC-based applications	Prof. Debei, Prof. Lancini	20	4	SI	SI (Report)		4
Space systems and their control	Prof. Francesconi, Prof. Lorenzini	20	4	SI	Written Exam	September 2015	4
Presentation of Research Proposal	Prof. G. Naletto	10	2	SI	SI (Write-up proposal)		2
Space optics and detectors	Prof. Naletto, Prof.ssa Pelizzo	20	4	SI	Written Exam	June 2015	4
Admission to Ph.D. presentation			1/3	SI	Presentation	November 2014	1/3
Attendance to admission presentation of new Ph.D. students			1/6	SI	Attendance only	October 2015	1/6
Attendance to admission presentation of new Ph.D. students			1/6	SI	Attendance only	October 2016	1/6
Attendance to admission presentation of new Ph.D. students			1/6	SI	Attendance only	October 2017	
Presentation after 1st year			1/2	SI	Presentation	October 2015	1/2
Presentation after 2nd year			1/2	SI	Presentation	October 2016	1/2
Presentation after 3rd year			1/2	SI	Presentation	October 2017	
15*2 hours long Specialistic Seminars offered by the Ph.D. School/Course (0.4 ECTS each with final discussion)	Various Professors	30	6	SI	Attendance + discussion/ presentation	From March 2015 to end of Ph.D.	4
OTHER EDUCATIONAL ACTIVITIES							
Title of the activity (Date/Period)	Teacher	Duration (hours) of activity	Attainable ECTS credits	Frequency (YES/NO)	Exam (YES/NO and type)*	Date of exam**	Attained ECTS credits
Electric Road Vehicles	Prof. G. Buja	48	6.0	SI	SI (Exam)		
External seminars, congresses, didactics support activities		32	1.67	SI	Attendance only		1.28
Summer Course on Power Electronics and Applications	Various Prof.	80	3	SI	Attendance and discussion		3
Total of ECTS credits attainable in educational activities (>30):			30	Total of ECTS credits attained in educational activities: date 25 08 2016			24

7. REFERENCES

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Thank you for your kind attention