

# Interactive Power Electronics Seminar (iPES) – A Web-Based Introductory Power Electronics Course Employing Java-Applets

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## Abstract

This paper introduces the Interactive Power Electronics Seminar - *iPES* - a new software for teaching a basic course on power electronic circuits and systems. *iPES* is constituted by HTML text with Java-applets for interactive animation, circuit design and simulation and visualization of electromagnetic fields and does comprise an easy-to-use self-explaining graphical user interface. The software does need just a standard web-browser, i.e. no installations are required. *iPES* can be accessed via the World Wide Web or from a CD-ROM in a stand-alone PC by students and professionals. Since the Java applets are simple to handle, a student can immediately start working and can fully concentrate on the theory of a problem. Due to the underlying software technology *iPES* is very flexible and can be used for on-line learning and easily integrated into an e-learning platform.

The aim of this paper is to give an introduction to the *iPES*-project and to show different areas covered. The e-learning software as presented at the conference is available at no costs at [www.ipes.ethz.ch](http://www.ipes.ethz.ch) in English, German, Japanese and Korean. More translations, e.g. into Spanish and French will be available soon. The project is still under development and the web page is continuously updated in four-week intervals.

## 1 Introduction of the *iPES*-Project

Using new media and information technology in the classroom can not only make studying more attractive to the student, but might make also teaching much easier [1], [2]. Especially in engineering classes complex technical problems have to be presented in a way which is easy to follow and understand. If, additionally, the system to be described shows dynamic behavior and/or numerous different switching states teaching becomes difficult in case only words and static pictures are at hand. Based on this experience the authors started the development of *iPES* in mid of year 2000. After implementing some basic examples a library of Java classes was established which does allow to do the programming an applet for a new circuit topology within a few days. The project is online [3] since July 2001 and a free download of the whole software

is available since January 2002. Within March 2002 the number of downloads per month has increased to over 600. Up to now three papers have been published on *iPES*, where the basic concept has been described [4], a comparison of *iPES* to other e-learning projects and modern teaching activities in power electronics has been given [5] and the teaching of space vector calculus by *iPES* has been described in order to give an impression how *iPES* could be employed in teaching [6].

Besides students also engineers working in the industry have identified interest in *iPES*. E.g., a Japanese company has started to employ *iPES* in internal education making in order to achieve a higher efficiency in training engineers entering into the field of power electronics. Furthermore, there is interest from companies in incorporating *iPES* based animation into web pages in order to explain the basic concept of products in a direct, and attractive way to potential customers.

At the ETH Zurich the authors in addition to regular courses on power electronics running in the 5<sup>th</sup>, 7<sup>th</sup> and 8<sup>th</sup> semester have started to teach an undergraduate course in the 3<sup>rd</sup> and 4<sup>th</sup> semester in electrical engineering on Java programming. The course is on simulation and animation of basic power electronic circuits using Java and is very popular among students and does provide a possibility to introduce power electronics to students in an early stage.

## 2 Web-Technology

HTML-text and embedded Java-applets turned out to be an excellent choice for interactive web-based education, i.e. *iPES*. In order to keep development time and costs low the authors employ XML for storing all data used by the Java-applets. Projects using Java applets in different fields of engineering [7], [8], [9], [10] and for simulation in power electronics [11], [12], [13] can be found on the Internet in a growing number.

Although Java was not designed with extensive numerical computation in mind, it proved to be sufficient for circuit simulations and even simple calculations of electromagnetic field distributions as long as the programming is done

carefully and with minimum computation time in mind [14]. Since Java was designed for the Internet it was possible to make *iPES* available for a large audience within a very short time and with minimum effort.

One problem is that *iPES* is dependent on the web-browsers being currently available. While *iPES* works with highest efficiency (by far) on the Internet Explorer, Microsoft could remove Java from its browser in the future. On the other hand, Netscape's Java is not very efficient and the latest browser release (6.1) does not work properly with many *iPES*-applets. Therefore, a stand-alone Java-version of *iPES* is under development and will be available for a free download in the near future (additionally to the version with the Java-applets) in to be fully independent from future browser developments.

### 3 Teaching Power Electronics with *iPES*

#### 3.1 Contents of *iPES*

*iPES* currently does contain 30 Java-applets and therefore does provide an excellent basis for teaching an introductory course on power electronics including the subjects listed in the following:

- (1) DC/DC converters without output voltage isolation (continuous and discontinuous current mode)
- (2) DC/DC converters with high frequency output voltage isolation
- (3) Control-oriented basics of DC/DC converters modeling
- (4) Design of power electronic converters (types of power semiconductor devices, thermal design, magnetic components)
- (5) Single-phase diode bridge with capacitive smoothing, effects on the mains, power factor correction
- (6) Self-commutated single- and three-phase voltage DC link inverter, pulse width modulation, space vector calculus
- (7) Line-commutated three-phase half-bridge converter, rectifier and inverter operation
- (8) Series connection of line-commutated half-bridge converters, full-bridge converter
- (9) Parallel-connection of line commutated converters, inter-phase transformer
- (10) Anti-parallel connection of line-commutated converters, four-quadrant DC machine drive
- (11) Resonance converters, u-Zi-diagram.

#### 3.2 Interactive Animation

Studying or teaching of power electronics subjects is often difficult because there is a large number of possible reactions of a system to parameter changes and the conduction state of a power electronic circuit does go through a sequence of states also for stationary operation. The conventional way of presenting such challenging

contents is by a sequence of slides showing time- and/or parameter-dependent snapshots of the system behavior.

In *iPES* the Java-applets are capable of acting like movies and therefore do immediately show the dynamic system behavior. Additionally, the applets are interactive, i.e. do offer the possibility of an manipulation of system parameters with the mouse via a graphical user interface and do show directly the resulting time- and frequency behavior of the system. The added HTML text provides hints how to interact with the system in order to understand why certain system reactions do occur. As compared to classical approaches of teaching this way of learning does get the student actively involved. A further advantage is that the student could decide on the progress of the presentation of the material and/or could adapt the course individually.

While the professor presents a power electronic system in addition to using slides also by *iPES* (using a laptop and a beamer), the students are told to repeat the examples on their home computer and to try additional parameter variations. This results in a more active involvement of the student.

#### 3.3 Textbook

*iPES* is comprised by Java applets embedded into HTML pages. The HTML text does describe how to use the various applets but does not give details on the principle of operation of the power electronic circuits shown. This is because most of the applets are self-explaining and students usually dislike reading teaching material on a computer screen. Therefore, the authors have decided to write a textbook which will refer in detail to all *iPES* contents and, furthermore, will provide guidelines how to make most effective use of the Java applets for teaching and/or studying. There, e.g. variations of specific parameters of a circuit will be suggested and an interpretation of the results will be provided. The publication of the textbook is scheduled for early 2003.

#### 3.4 Example: Space Vector Based Current Control of a Three-Phase PWM Rectifier

A representative Java-applet for interactive animation is presented in the following.

Space vector calculus is very convenient for describing and understanding the behavior of three-phase PWM converter systems. There, instead of analyzing the time behavior of three phase quantities which are mutually dependent (for three-wire systems), a single time-dependent vector in the complex plain ("space vector") is considered. *iPES* does provide applets for studying the basics of space vector calculus in a very straightforward way.

In **Fig. 1** screenshots from an advanced *iPES*-applet are shown which is dealing with space vector based current control of a voltage DC link PWM rectifier system. There, a student could drag the mains voltage space vector with the

mouse in the complex plane (applet shown on the left-hand side of the screen). Furthermore, the relative turn-on times of the rectifier voltage space vectors incorporated into a switching state sequence are shown in form of bars in rectangular boxes. The power circuit of the system is shown by the top right hand side applet. There, the phase current flow is animated by colored moving dots. The symbols of the switches are changing between in on- and off-position according to the actual switching state. The applet below the power circuit applet shows the time behavior of the switching signals of the three phases within one switching period  $T_p=1/f_p$ . There, a vertical red line can be dragged with the mouse (time marker) which does allow to define an actual point in time. The currents paths in the power circuit applet are corresponding to the position of this time marker. This approach is very useful for explaining the basic function of a power circuit and is a main technique employed in *iPES*.

The bottom right-hand applet shows the time-behavior of the mains voltages and a vertical time marker which corresponds to the actual position and/or phase of the mains voltage space vector in the left-hand applet.

Technically speaking, all four applets shown **Fig. 1(a)** or **(b)** are interconnected. This means, e.g., that changing the mains voltage space vector phase or magnitude or the time marker position by dragging with the mouse does result in immediate updates of all data in each applets.

The graphical user interface has turned out to be very intuitive. All symbols or objects shown in red could be clicked and dragged with the mouse. The HTML text explains only what parameter changes could be performed but do not give descriptions of the circuits shown. The explanation of the principle of operation of the circuits is still up to the teacher and/or will be provided in the form of a textbook.

## 4 Teaching Basics of Electromagnetic Fields

### 4.1 Background

Inductive components like inductors and transformers are basic elements in power electronic circuits. Understanding the functionality and the dimensioning of these components is essential, therefore. After attending introductory courses in basic electrical engineering many students still lack a detailed understanding of the physics of these magnetic devices.

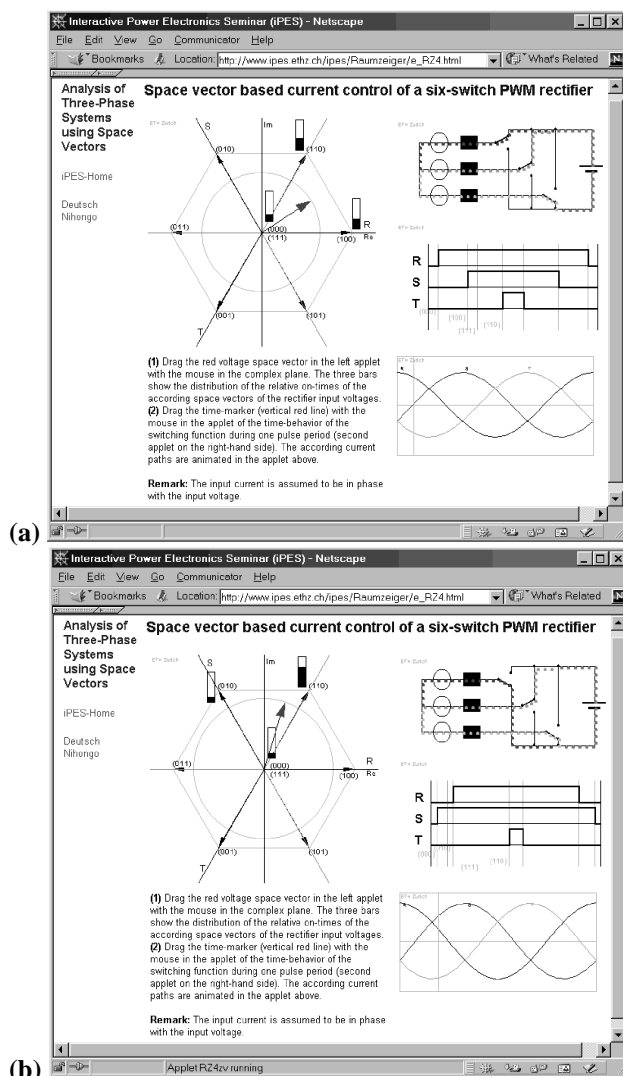
This has given reason for extending *iPES* with Java applets showing the physics and/or magnetic fields of inductors and transformers.

The main idea of *iPES* is to provide means for changing parameters of a depicted power system by dragging with the mouse and to immediately show the resulting changes of the time-behavior of characteristic system quantities. This means that the system simulation has to be performed within a few milliseconds in order to give the user the feeling of an immediate response. Performing circuit-oriented simulation within such short time intervals is possible but calculating electromagnetic fields typically is much more time consuming especially if finite element methods are employed.

Experiments on fast algorithms for field-calculations by Java applets are currently under way at the ETH Zurich. First results are very promising and will be published in near future.

### 4.2 Example: Rotating Magnetic Field

The idea of this applet is to give the student a deeper understanding of the formation of a rotating magnetic field which is essential for understanding the principle of operation of three-phase AC machines. Especially, the

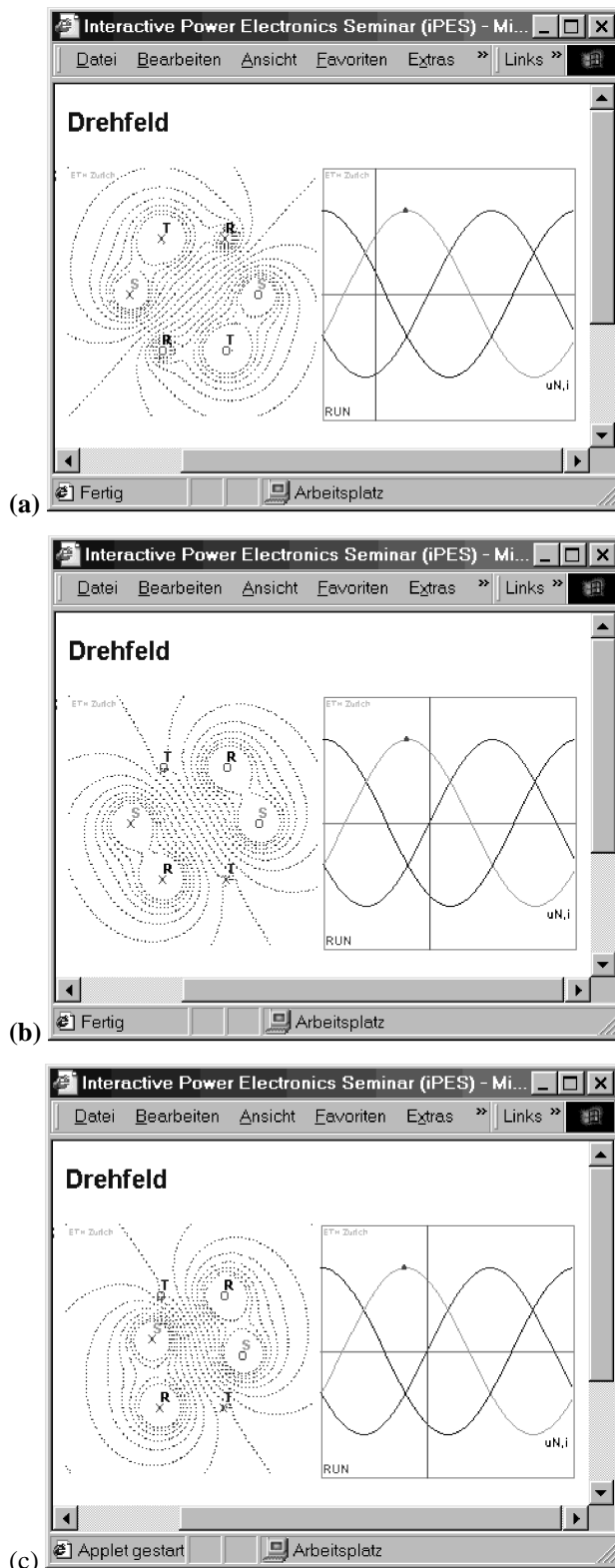


**Fig. 1:** Space vector based current control of a three-phase PWM rectifier. **(a):** space vector of the mains voltage for  $0 < \varphi_U < \pi/3$ , actual switching state is (110). **(b):** space vector of the mains voltage for  $\pi/3 < \varphi_U < 2\pi/3$ , actual switching state is (010).

relation between the physical positioning of the wires and/or phase windings the phase displacement of the currents fed into the windings should be made obvious.

**Figure 2(a)** shows the magnetic field of a three-phase winding system where the individual phase windings (lying on a circle) are displaced by  $120^\circ$  in space. Each winding is formed by a wire carrying the corresponding phase current in positive z-direction and a second wire carrying the current in the opposite direction resulting in a total of six wires as shown in the applet. At the right-hand side the time-behavior of the currents in the phase windings is shown. A vertical red time-marker can be dragged with the mouse in order to change the actual point in time considered. While dragging the time-marker the applet responds immediately and the magnetic field does change accordingly (**Fig. 2(b)**).

The wires in the left-hand side applet showing the rotating magnetic field could also be dragged into new positions with the mouse. The change of the physical location of the wire does result in a distortion of the magnetic field as shown in **Fig. 2(c)**. Pressing the “RUN”-bottom in the time behavior applet does continuously move the time marker and correspondingly does result in a rotating magnetic field. Furthermore (not shown here), the amplitude of the phase currents could be changed by dragging with the mouse what does result in a changing field intensity.



**Fig. 2:** Rotating magnetic field. (a), (b): Rotating magnetic field for different positions of the time-marker in the applet showing the time behavior of the three-phase current system supplying the windings. (c): changing the position of, e.g., the winding of phase S does result in distortion of the rotating magnetic field.

## 5 iPES+ Supporting the Dimensioning of Novel Three-Phase PWM Converter Systems

### 5.1 Background

Besides developing *iPES* for educational purposes the authors recently started an *iPES+* project (see also [www.ipes.ethz.ch](http://www.ipes.ethz.ch)) for demonstrating the operating principle of modern three-phase power converters of higher complexity which are employed by industry today or could be of interest for application in future. The applets compiled in *iPES+* should give an engineer an introduction into the basic principle of operation of the system considered, and should facilitate the system dimensioning. Furthermore, links to relevant papers and brief technical descriptions of the converter systems are given.

As an example the description of the Vienna Rectifier 1 [15] as contained in *iPES+* shall be given in the following.

### 5.2 Example: Vienna Rectifier 1

The Vienna Rectifier 1 is a unidirectional three-phase three-switch three-level PWM rectifier (AC/DC). The applet shown in **Fig. 3** gives a very detailed insight into the principle of operation of the power circuit (top left), the according input voltage space vectors (bottom left), and the time behavior of mains voltages and mains currents (top right). Furthermore, the time behavior of the switching signals and of characteristic system voltages and currents within one switching period are shown (bottom right).

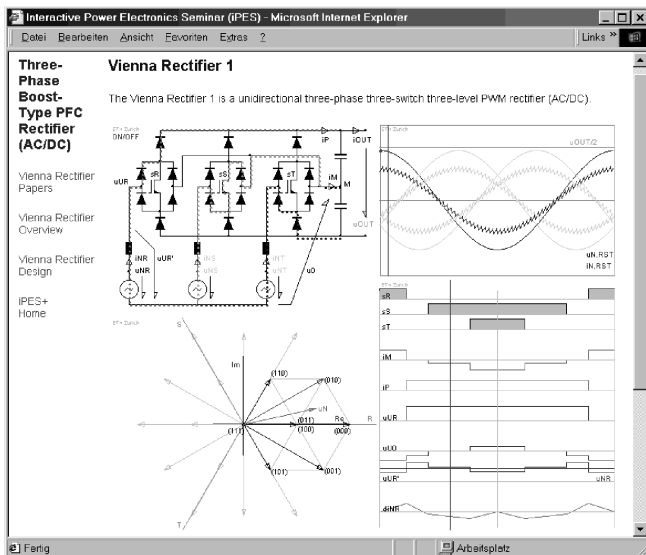


Fig. 3: Basics of the functionality and space vector calculus.

One can drag a vertical time-marker in the mains phase voltage applet (top right) in order to define a point in time to be considered. The according time behavior of the signals, voltages and currents within a switching period is automatically updated in the applet below (bottom right). In the pulse period applet a vertical time-marker can be dragged with the mouse and does define a point in time within the considered switching period. The corresponding phase current paths are shown in the power circuit applet (top left) while the actual space vectors (applet bottom left) is highlighted in red. Furthermore, the amplitude of the mains phase voltages can be changed by dragging with the mouse.

By changing the key parameters it is simple to investigate the system for different operating conditions and parameter combinations. Since switching patterns for all operating points are given, the applet furthermore is very helpful for debugging a simulation or a hardware prototype.

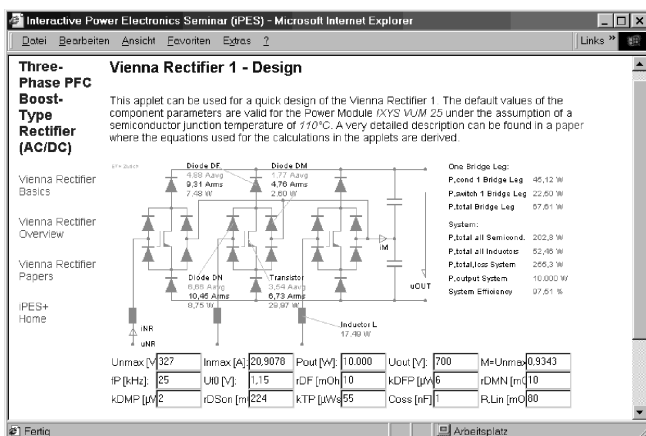


Fig. 4: Java applet facilitating the dimensioning of the Vienna Rectifier 1 power circuit.

The applet shown in Fig. 4 can be used as a basis for the dimensioning of the Vienna Rectifier 1 power components.

The default values of the component parameters are valid for the Power Module IXYS VUM 25 under the assumption of a semiconductor junction temperature of 110°C.

The user specifies the input- and/or output voltage- and current-levels, the output power and the switching frequency. The Java applet calculates all rms- and avg-values of the currents in the semiconductors. By specifying various semiconductor parameters the applet also calculates switching- and conduction losses each semiconductor component and does provide information on the total power losses of a bridge-leg.

Furthermore, a HTML page (not shown) lists the characteristics and advantages of the Vienna Rectifier 1 (as compared to the two-level six-switch boost-type PWM rectifier systems) and lists possible fields of applications. Another HTML page provides a collection of key papers which have been published on the Vienna Rectifier 1 (Fig. 5). The material does give a detailed description of the principle of operation, and of different control concepts, and does show experimental results.

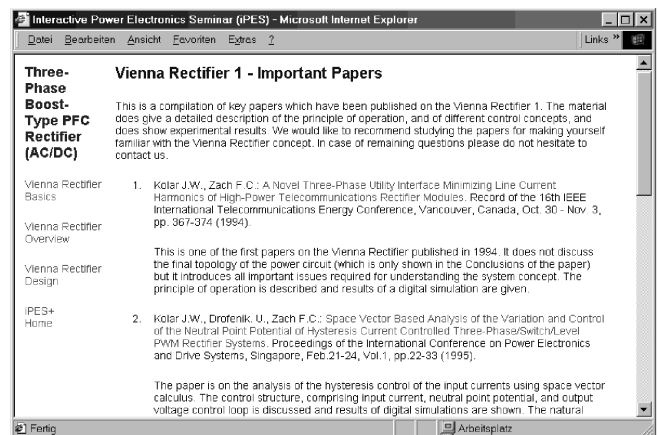


Fig. 5: Collection of key papers published on the Vienna Rectifier.

## 6 Future Developments

*iPES* as a basic course on power electronics will be finished up in near future. In a next step a textbook being coordinated with *iPES* will be published in early 2003. The book will cover the theory of operation of all systems shown and will give recommendations how to make most efficient use of *iPES* in studying and teaching.

*iPES+* will be finished in year 2002 and will be extended in the future each time a new system or circuit topology becomes relevant to the industry. Besides *iPES+*, an Advanced Power Electronics Seminar for the teaching of power electronics in graduate level courses will be issued in the *iPES*-style.

Several colleagues expressed the desire to have the *iPES* material available in native language. Therefore, with the help of power electronics specialists all over the world

further translations will be added. German, English, Japanese and Korean are available at the time of this writing (April 2002). Spanish and Chinese will be available soon.

Besides circuit simulation applets for studying the electromagnetic and thermal fields in passive power electronic components (for example, inductors and transformers) will be provided because passive components will become increasingly important as future power electronic systems should show an increased power density and efficiency. There the calculations of the fields will be done based on finite element method. First experiments are currently under way.

In order to make *iPES* independent from future browser development furthermore a stand-alone Java-version of *iPES* will be developed and will be available for a free download in addition to the applet-based course.

## 7 Conclusions

In this paper a new operating-system-independent e-learning software – *iPES* - for education in power electronic circuits and systems has been introduced. *iPES* could be used via the Internet or on CD-ROM due to the combination of HTML text, Java applets and XML. The Java applets are inserted into the HTML text and are written to provide interactive animation, dimensioning and circuit simulation and calculation of electromagnetic fields with an easy-to-use and self-explaining graphical user interface.

*iPES* currently does constitute a one semester interactive course on fundamentals of power electronic circuits. Due to the underlying software technology *iPES* is very flexible in use and could be employed e.g. in addition to conventional teaching. Interactive animation also is very efficient for studying because the student is actively involved.

*iPES* is available for free download in English, German, Japanese, Korean (more languages will be available soon) at [www.ipes.ethz.ch](http://www.ipes.ethz.ch). The whole project is still under development and the web page is updated continuously in four-week intervals.

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