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Security Through Antiquity

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FEATURES

ON THE COVER:
Looking back to ensure a secure future.

DEPARTMENTS & COLUMNS

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The challenge

by Cristian Quintero

Being an engineer is a tough task, the world is changing fast, and sometimes we don't even realize what's going on around us. There are electric cars on the highways, wallets for virtual money, high-speed Internet connections in our hands, artificial intelligence recognizing faces or voices, emoticons replacing words, and more. The innovations that have emerged in the last decade include engineering as an essential part of their invention.

This revolution is just starting, and it's not a surprise that the world needs new engineers who are capable of managing current technologies and designing new innovations for the future. This is an excellent time for you to decide what you want to do with your life—after you earn your degree—because every day it become more difficult to stand out in the market.

Making a big decision like this is not easy, but life is about taking risks. I have a personal manta that has worked for me for a long time, and it can work for you: "Do not waste time dreaming of great far-away opportunities; start to work and improve yourself right now. Someday, a small opportunity will come, and those are often the beginning of great and amazing things."

We also have different resources in which we can find the support needed to keep going. The IEEE is one in which you will find personal and professional satisfaction. When you get involved in the IEEE, you will make friends around the world, many of whom have dreams like yours. You will likely also meet professors from the best universities who are ready and willing to guide you on your journey. But the most important thing is to make a decision, take the risk, and start; only then will you find your path.

Take advantage of your opportunities right now, because this is our generation's moment.

The advantages of our generation are many: information is easily accessible from almost everywhere, so we can learn anything whenever we want and wherever we are located. This allows us to be more creative, able to invent new businesses without borders, and/or work for a company while being located outside of a physical office. Facebook Cofounder and Chief Executive Officer Mark Zuckerberg once said, "The biggest risk is not taking any risk … in a world that is changing really quickly, the only strategy that is guaranteed to fail is not taking risks." Take advantage of your opportunities right now, because this is our generation's moment.

Do you remember Barney Stinson from the television comedy *How I Met Your Mother*? One of his most memorable phrases was "challenge accepted," so if you accept the challenge, it's going to be "legen … wait for it … dary," legendary! Good luck.

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The Student Professional Awareness Experience Program

by J. Patrick Donohoe

Is your IEEE Student Branch looking for a way to involve a large number of students in an activity that provides valuable skills for your members? If so, your branch should consider an event based on IEEE's Student Professional Awareness Experience (SPAx) program.

The focus of the SPAx program is to develop key nontechnical skills that are crucial for success in the workplace but are not taught in the classroom. Engineering is broader than the various technical skills covered in the typical engineering curriculum. Nontechnical competencies are just as critical to engineers as their technical training. The student professional awareness activities of the SPAx program are oriented to enhance the leadership, career, and professional development skills of engineering students.

The "x" in SPAx is a variable. That means your student professional awareness event can take on whatever format fits the needs of your Student Branch. Your event could be a conference with an invited expert speaker, a series of activities focused on honing career skills, a social event to foster networking and team-building skills, a design contest, a tech talk, or any other format, as long as it focuses on one or more of eight prescribed areas. These eight areas are

1) career development
2) professional integrity
3) personal skills
4) engineers and public policy
5) leadership in professional organizations
6) the practice of innovation
7) the art of communication
8) humanitarian grand challenges.

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The student professional awareness activities of the SPAx program are oriented to enhance the leadership, career, and professional development skills of engineering students.

You decide what type of event works for your branch, and the IEEE provides the support to implement your ideas. Student Branches are encouraged to be creative in organizing their own professional awareness events. The traditional conference format, ventures, tech talks, or resume workshops are just some of the options to engage your members in professional awareness activities.

There are four basic steps involved with a successful SPAx event. To initiate a SPAx event, the Student Branch submits a few bits of information to the IEEE, and a SPAx coordinator in your area will follow up shortly to discuss your event plans. Then, the branch decides what type of professional awareness event would be interesting to its members. Any event or budget can be considered. The IEEE only asks that you submit an event description when seeking official approval. Once the IEEE approves your event, it's time to plan your budget, funding, venue, program, and marketing. After holding your event, your branch sends the IEEE a report on your results and the lessons learned.

Hosting a SPAx event is a huge benefit for not only the students who gain skills through participation in the event but also for those who organize the event. Organizers can network with real-world companies as the Student Branch seeks sponsorships for the event. As a resume builder, organizers can point to their demonstration of leadership skills.

For more information on the SPAx program, visit https://ieeeusa.org/spax/index.html. You can learn from the newly revamped experience page, created specifically as a platform for Student Branches around the world to share their innovation with each other.

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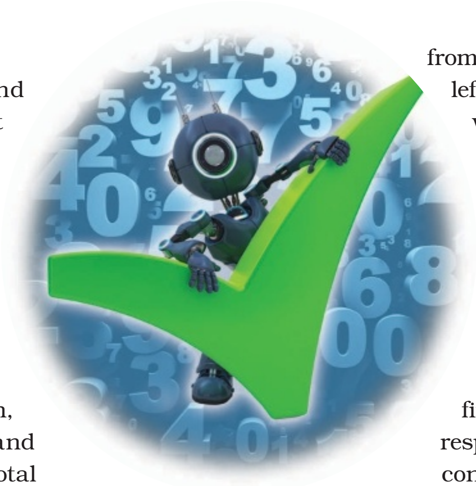
by Athanasios Kakarountas



NUMBERS—© CAN STOCK PHOTO/123DARTIST,
ANDROID—© CAN STOCK PHOTO/KIRSTYPARGETER

Solution #1: No Bull

It is difficult to take the 17 oxen and divide them by two to give to the first son, by three to give to the second son, and by nine to give to the third son, so an aspiring mathematician borrowed an ox and brought it to the cattle farmer's house. The total number of oxen now is 18 oxen and is divisible by two, three, and nine.

The first son will receive nine oxen, the second son is gifted six oxen, and the last son will get two oxen. The total number of oxen the three sons will get from their father is $9+6+2=17$. We are left with one ox, and the mathematician will return the ox to the owner.

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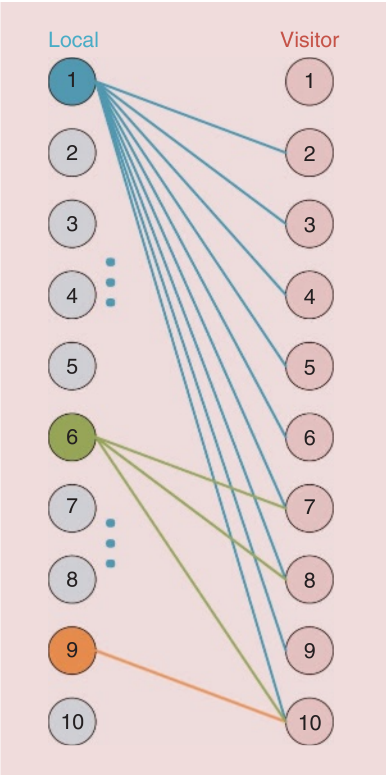
Solution #2: The Birthday Boy

To solve this problem, remember that a normal year (nonleap year) counts 52 weeks plus one spare day, thus only one day is repeated 53 times. While, in a leap year, days that are repeated 53 times are the first and the second day of the year, respectively. This information allows us conclude that the first day of January was on Saturday and, taking into account that January has 31 days and February 29, the first day of March was on a Wednesday. Anthony was born on Wednesday, 1 March.

Solution #3: Match Point

As a national team can't play against itself, every team must play nine matches as local. Team number 1 has to play with teams numbered 2, 3, 4, ..., 10 (nine matches in total). Then, team number 2 has already played with team number 1, so it only must play against 3, 4, ..., 10 (eight matches in total). If we continue, we see that team number 6 plays with teams 7, 8, 9, and 10, because teams 1, 2, 3, 4, and 5 were already considered.

So, we add the matches of team 1, team 2, ..., team 9 (team 10 doesn't have matches pending to play).



$$\text{matches} = 9+8+7+6+5+4+3+2+1$$
$$\text{matches} = 45.$$

Since games are played as both a local and a visitor, every match is repeated, so

$$\text{total matches} = 45 * 2 = 90.$$

The number of matches played in the South American World Cup qualifiers is 90.

Solution #4: Time to Get a New Clock?

Considering that the arrow indicating the hour is stopped in the location of the 23rd minute, this means that it has completed 3/5 of the distance between minutes 20 and 25. Moreover, the fraction 3/5 of 1 h indicates 36 min, leading to the conclusion that the correct time is 4:36 p.m.

Solution #5: A Prime Situation

Notice that the sum of the last digit of these numbers is $4+6=10$. This is an even number, so the smallest prime number required is 2.

P

Technology—A two-edged sword

Raymond E. Floyd

From the time mankind discovered rocks could be used to open coconuts or break bones to access marrow, it also learned that the same rock could be used to attack others of the human race—rocks were effective weapons. Thus, the story of the two-edged sword of technology began. From stone knives, spears, and arrowheads that provided advances in technology for survival, each also became a better device with which to attack, or defend, territory. From stone, to bronze, to iron, each advance benefitted mankind while also being used to extend conquests over others.

As mankind moved through technological advances from bow and arrows to gunpowder and beyond, the positives and negatives of each advance could be found. The question that could be asked is, "Is mankind destined to continue this destruction with each advance in technology?" One would hope the answer is an emphatic "No!," but only time will provide an answer to that question.

It is interesting to look at some areas of technology and note how each has been developed for the benefit of mankind and then adapted into a tool of destruction. Perhaps one of the earliest advances in transportation was the simple canoe or similar conveyance. From a beneficial application enabling mankind to move across great distances using rivers, streams, and even oceans, the advent of paddles, oars, and sails helped people to move about and between continents. From that early beginning, fast-forward in time to vast armadas that cruise on and beneath the surface of our oceans, with

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We must remember the dual-edged nature of technology and strive to provide all of the safeguards possible to dull one side of the sword.

great firepower to defend or attack as the need arises—another technology bent and shaped into both a benefit and a detriment.

Also consider manned flight. The benefits are immediately evident with people and cargo able to move anywhere in the world in a matter of hours, enabling relief to quickly gather at sites of natural disasters. Then there is the more mundane application for business or personal travel. Manned flight can be extended to include space travel, and the technology developed provides many examples to benefit mankind.

In contrast, look at the bomber and fighter aircraft used in conflicts between opposing ideologies, again, the doubled-edged nature of technology. Similarly, nuclear power was an instrument first developed for use in war, the atomic bomb at Hiroshima. Since its first use in World War II, the power has been harnessed and applied as a source of power for the generation of electricity for the benefit of millions. Even today, hundreds of nuclear-armed missiles remain available for the potential holocaust of mankind. One can hope there are no itchy trigger fingers in that arena.

Exploitation and fraud

Not all technological advances are paired with a counterpart of war. Consider the advances in computer systems and applications that have advanced communications and other facets of life we now enjoy. Where would we be without the Internet, texting, or online shopping, banking, and similar applications? While some may argue that all of these advances are not in the best interests of mankind, it is in our nature to continue to adapt, expand, and develop new uses for such tools. It could also be argued that many of these new tools have application within instruments of war, especially in the adaptation of computers and associated systems found in weapon platforms today.

Unfortunately, these great advances are also used in a manner not to benefit all people but to simply profit the user in instances of fraud, exploitation, or other opportunities to cheat others of their financial well-being. We also see too many instances of the use of the Internet in bullying others or otherwise using the technology for questionable uses, such as pornographic material, racist commentary, or other similar personal adaptations. The Internet can also be used to support terrorist organizations, providing instant communications in planning their next attack.

It will be interesting to watch the development and expansion of the Internet of Things in the days to come. There are many assurances on the safety and security features included in the remote controls of homes, power grids, and other features that will affect millions of lives across the world. It remains to be seen if all of the efforts to encrypt, password protect, and other security features will keep out those who would use the system to move forward their own agenda.

From a historical perspective, those who would use the system for their own purposes have not been prevented from bending and breaking systems thus far. One might say that technology is bad in that it continues to provide methods of destruction. Perhaps there is truth in that, but I believe there are many more applications of technology that assist mankind. I would not like to return to the Stone Age, since I find my current lifestyle too comfortable. There will always be those who would bend new technology to further their own agenda, especially when the goal is to benefit only themselves or their organization. We must continue to work to provide safeguards against such use.

Most professional organizations have a code of conduct or code of ethics. It is interesting to note that in the IEEE's Code of Ethics, one item in particular addresses the double-edged nature of technology. Item 5 states, "To improve the understanding of technology; its appropriate application, and potential consequences…". In those few words, the organization lays the foundation for its members to understand and follow the principles of developing technology for the good of mankind and understand how it can be misused by those with bad intentions. We must remember the dual-edged nature of technology and strive to provide all of the safeguards possible to dull one side of the sword.

Read more about it

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Raymond E. Floyd (r.floyd@ieee.org) earned a B.S.E.E. degree from the Florida Institute of Technology in 1970, an M.S.E.E. degree from Florida Atlantic University in 1977, and a Ph.D. degree in industrial management from California Coast University in 2009. He spent 26 years with IBM, retiring in 1992 as a senior engineer. He is a Life Senior Member of the IEEE, a life senior member of the Society of Manufacturing Engineers, and holds four patents. He has served as a program evaluator for the Engineering Technology Accreditation Commission of ABET (ETAC/ABET) for 20 years and is an associate editor of *IEEE Potentials*.

P

Windows ME: Using antiquated software to learn about security

Andy Luse, Amjad Al Marzooq, and Jim Burkman

How can a course on hacking not be fun? While this type of class can be an extremely enjoyable and rewarding experience, the reality is that many students tend to become disenchanted once the coursework begins. Many students have grown up watching movies and television shows that depict hacking as a quick, graphically intense process where the attackers effortlessly get whatever they need from whomever they want and instantaneously use this gathered information to their advantage. The reality is that much of hacking involves a long and drawn-out process, whereby attackers meticulously scan machines and services looking for obscure exploits.

Keeping the attention and motivation of students despite these unrealistic expectations can be challenging from an instructor's perspective. In this contemporary culture of instant information and immediate gratification, success in teaching hinges on entertainment as much as instruction. You can't expect high-quality course content to reach bored and inattentive minds.

Games are often used to teach computer security and can also be embedded into labs. Our goal was to try and effectively teach cybersecurity without the layer of abstraction introduced with gaming analogies.

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This article features a classroom project that leverages the idea of "security through antiquity" (Hruska, 2008) by analyzing the effects of vulnerability assessment tools on successive versions of the Windows operating system (OS) in a classroom setting. The results provide anecdotal evidence of high student interest and involvement with the older technology and also show important differences between the generations of Windows OSs.

Security through antiquity

Hruska (2008) wrote about the end of the Windows for Workgroups 3.11 life cycle and considered that older systems might actually be more secure than newer systems due to "security through antiquity," a state where the simplicity and lack of desirability of older systems made them less attractive targets for hackers as compared to newer, more widely used systems. There is anecdotal evidence to support using older systems for a better security posture. As systems continue to evolve, they bring with them new designs and a wide variety of enhancements. While these added features make newer versions friendlier, more sophisticated, and feature-rich as

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compared to older versions, the newer systems also provide attackers with a bigger attack surface when compared to older systems (Lata, 2014).

Conversely, given the tendency for adoption of newer technology as it is released, older systems are not as popular or appealing to attackers as compared to newer, more recently released systems. Consider the impact of malware on various versions of the Microsoft Windows OS as described in the report published by Lata. In it, Microsoft admitted that malware is less of an issue on XP than on Windows 8. The infection rate on Windows XP was 2.4% while the rate for Windows Vista and Windows 7 stood at 3.2% and 2.6%, respectively.

Classroom project

The security through antiquity concept offered a fun opportunity to engage students in a classroom project and to test this proposition. This project was presented as an in-class lab exercise as part of an applied information assurance security course designed to support Oklahoma State University's mission as a National Center of Academic Excellence in Cyber Defense Education and Research. Students were primarily juniors or seniors earning their undergraduate management information systems degree.

Students were first asked in the classroom which would be better from a security standpoint, older or newer OS software. In response, nearly all of the students answered "newer." Students were then provided with a lab environment that allowed them to install a wide range of Windows OSs.

Given that we wanted to investigate the proposition of OS security as a function of age, we needed an OS that had been around for some time to test this proposition. The many variants of the Linux OS met this criteria, but general student knowledge of Linux systems led to concerns about student engagement. Microsoft Windows was chosen as it has had many versions—dating back to 1985 with the release of Windows version 1.0—and all of our students have used one or more versions of the system.

Only consumer client versions of Windows were analyzed including Windows 95, 98, 98 Second Edition (SE), ME, XP, Vista, 7, 8, 8.1, and 10. While several versions of Windows existed prior to 95, this version was chosen as the starting point due to the more accepted network connectivity built into the OS (i.e., the increasing popularity of the Internet drove Microsoft to make this version more network-friendly).

Each of the OSs were installed as a virtual machine using VMware. The initial version of each OS was installed without any updates or service packs to provide a common starting point for each machine. For the newer Windows versions (Vista through 10), the firewalls were disabled to allow for equivalent network access to the machines. When finished, the students had working versions of Windows with network connectivity on a private subnet.

The security of the machines was then analyzed by the students using several programs. Nmap was used to scan the machines for open ports/services, while both Nessus and Nexpose were then used to scan the machines for vulnerabilities. These three products were chosen due to their popularity as scanning tools and also to provide redundancy in the scans in case one program identified a vulnerability that another did not.

Reviewing the results

The results of the Nmap port scan are shown in Fig. 1, where it is evident that older versions of Windows have less open/listening ports than newer versions of the OS. A typical Windows 95 machine has one open port compared to Windows 10, which has ten open ports that are actively listening for a connection. Open ports offer potential avenues of access for hackers because for every open active port there is a program "listening" for connection attempts. Any vulnerabilities in these programs translate to opportunities for exploits that allow an attacker access to the target machine. The students in the course were all taught about these vulnerabilities in previous classes that were prerequisites to the current course.

Figure 2 shows an overview of the number of critical, high, and medium vulnerabilities found by both Nessus and Nexpose. While the older OS versions (95 through ME) and newer OS versions (Vista through 10) show a low number of vulnerabilities, the number of vulnerabilities is still less in the older OS versions. Each of the older versions shows one severe vulnerability for Nexpose, while the newer versions show two critical vulnerabilities. Nessus also reported one critical vulnerability for Windows 95, 98, 98 SE and ME, but, in each of these cases, the reported vulnerability stated only that it was an out-of-date OS. Given that it did not cite a specific vulnerability, these were removed.

Furthermore, each of the older versions showed no medium vulnerabilities from Nessus, while each of the

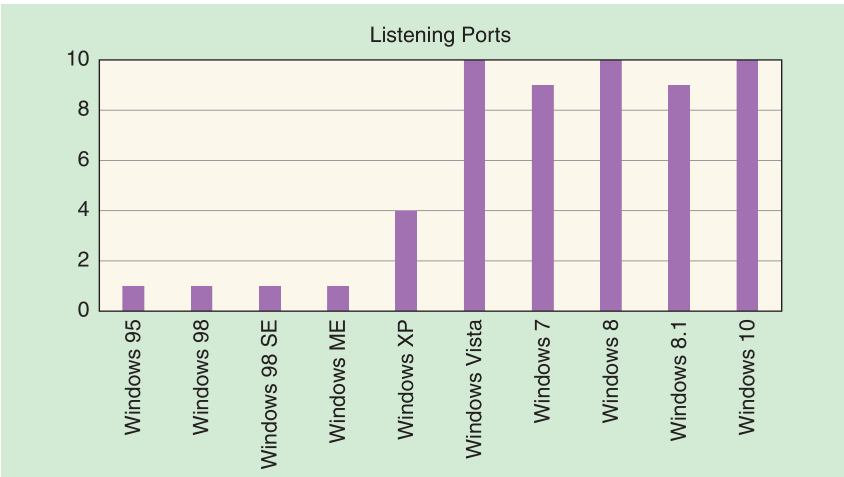

FIG1 The Nmap scan of listening ports for Windows OSs.

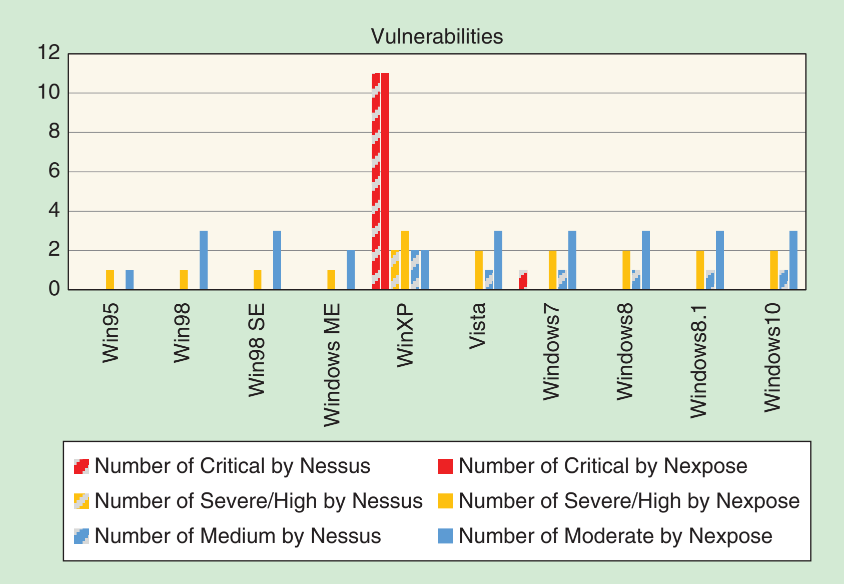

FIG2 The Nessus and Nexpose vulnerability scans by OS.

newer versions reported one. The older versions also showed anywhere from one (Win95) to three (Win98) medium vulnerabilities from Nexpose, while all of the newer versions revealed three vulnerabilities. Of special note is Windows XP with 11 critical vulnerabilities, two (Nessus) to three (Nexpose) severe vulnerabilities, and two medium vulnerabilities. Also, Windows 7 showed one critical vulnerability from Nessus.

Student responses

This project provided anecdotal evidence that the students were engaged and enjoying themselves with the learning process. The old CD media was novel to the students and brought remarks such as "I can't believe this hologram on the Windows ME CD." Seeing some of the older versions of Windows brought back childhood memories of either using those systems or hearing about them from their parents. The older installation processes brought up additional questions like, "What is a boot disk?", "Why do I have to install DOS before Windows?", and "Why doesn't it recognize my CD-ROM?" Each of these events presented a learning opportunity and helped the students understand how streamlined the current installation processes have become.

After completing the scanning, the students were asked to reflect on their findings. Most were surprised that the older OSs were much less liberal with regard to the number of ports—logical network access points—that were open by default. Students started to verbally question in class what ports are open and available in newer OSs and whether applications and processes should be less open by default. Many surmised that the built-in firewall on the newer OS versions was the only thing standing between it and utter doom. Rather than being overwhelmed by the statistics, the students used that data as an opportunity for critical thinking that most of them absorbed quickly.

Conclusion

Courses on hacking are becoming more popular in information systems curriculum and are necessary to train ethical hackers in the penetration testing skills needed to secure information systems. While many students are expecting the glitz and glamor portrayed in the media, hacking rarely elicits the immediate satisfaction as seen on television. By utilizing older OSs in a hacking course, students learn skills necessary for succeeding professionally while also analyzing the proposition of "security through antiquity."

Read more about it

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An introduction to soft-core processors and a biomedical application

Dominic Romeo, Joseph LaMagna, Ian Hogan, and James Squire

Despite the ubiquity of microcontrollers, widespread use of soft-core microprocessors is much less common. Most undergraduate curricula have a digital course involving field-programmable gate array (FPGA) programming, in languages such as VHDL or Verilog, and separately have a microcontroller course that uses the C language. But few synthesize these two topics to involve programming an FPGA to simulate a microcontroller.

This article details a senior-level elective course in which students designed a chemotherapeutic cancer research device using a soft-core processor at the heart of their product. The students describe how they chose to use a soft-core processor and how the implementation involved many nights of struggle, culminating with debugging at 70 mi/h in a car to make the delivery deadline.

What are soft-core processors?

Microcontrollers are familiar to most electrical engineers. The word *microcontroller* is commonly associated with the PIC and ATMega chips and development boards such as the Arduino and Raspberry Pi, a few of the popular and widely supported microcontrollers and development boards in use today by makers, students, and hobbyists. Microcontrollers pack a lot of functionality on a single chip, but for bigger or faster tasks, one may have to turn to FPGAs. When FPGAs are mentioned, engineers often begin to sweat a little. For many, FPGAs bring back memories of digital design and painful lines of hardware description language (HDL). Modern design tools have changed this and allow anyone needing the flexibility and performance of FPGAs while avoiding the difficulties of HDL programming.

So what is a soft-core processor? A soft-core processor is a program prewritten in HDL that provides a processing core that runs on an FPGA. It allows the programmer to define peripherals such as general-purpose input/output lines (GPIOs), serial parallel interfaces (SPIs), and universal asynchronous receiver/transmitters

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If a project calls for both a microcontroller and FPGA, a soft-core processor can decrease the overall printed circuit board (PCB) footprint, speed development time, and permit more flexible redesigns by implementing both on a single chip.

(UARTs) at compile-time so he or she can design a powerful embedded system uniquely customized to his or her requirements. Need a system with 40 pulsewidth modulated (PWM) outputs, a 16-b-wide parallel output port, and 12 serial ports? No problem. With the design tools available today, one can design an embedded system with a soft-core processor without writing a single line of HDL.

FPGA design tools such as Xilinx Vivado define the soft-core processor using graphical drag-and-drop operations. Then the C++ program that runs on the soft-core processor is compiled using a different design tool such as the Xilinx software development kit (SDK). On power-up, the hardware design is loaded onto the FPGA to create the soft-core processor and any additionally defined peripherals. Then the C++ program is loaded onto that soft-core processor, and finally the program executes.

FPGAs have development boards just as do many microprocessors. These development boards are great places to start designing embedded systems that use a soft-core processor. A relatively new development board for the Artix 7 FPGA is the ARTY by Digilent. What makes the ARTY particularly interesting is that it was designed with the MicroBlaze soft-core processor in mind. The ARTY reference page provides several getting-started examples using the MicroBlaze. The ARTY sports 256 MB of external random access memory (RAM), external flash memory for storing both the FPGA binary definition file and the C program that it runs, and a USB UART port to program the device. In terms of input/output (I/O), the ARTY boasts the familiar Arduino Uno footprint and an assortment of peripheral modular (PMOD) connectors; switches; push buttons; and red, green, and blue light-emitting diodes.

Advantages

In the Vivado design environment, digital logic is defined using a block diagram rather than writing traditional HDL code (Fig. 1). That's right, no HDL is needed. Those who have used LabVIEW will see some similarities with using the Vivado block design tool. Adding a soft-core processor, such as the MicroBlaze, becomes as easy as dragging and dropping from a toolbox, and its peripherals are defined using a setup wizard. Wiring blocks are done by simply clicking and dragging. Vivado even automatically makes the basic connections to implement bare-bones microcontroller functionality.

If a project calls for both a microcontroller and FPGA, a soft-core processor can decrease the overall printed circuit board (PCB) footprint, speed development time, and permit more flexible redesigns by implementing both on a single chip. A soft-core processor allows the user

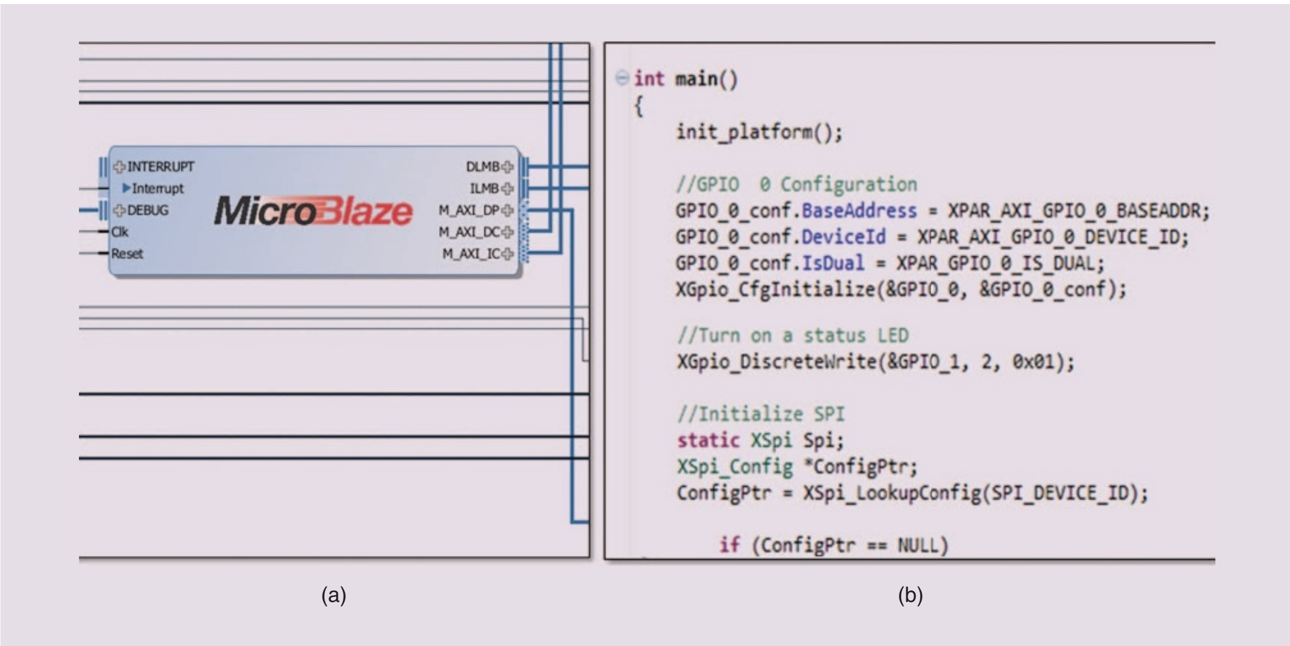

FIG1 (a) The part of a block design implementing a MicroBlaze soft-core processor. This shows the ease in implementing a soft-core processor using powerful design tools such as Viviado, which turns soft-core microprocessor design into a drag-and-drop operation. (b) Part of a program designed to run on this MicroBlaze that configures its GPIO and SPI interfaces at run time. Programs are written in C++, a language familiar to most engineers.

to customize the functionality of the microcontroller. Setup wizards let the programmer choose any combination of I/O, microprocessor and SPI clock speeds, amounts of RAM, and, in some cases, interfacing logic levels. If a project calls for more computing power, more cores can be added, all operating simultaneously, while the FPGA supplies the glue logic needed to connect them to outboard peripherals.

From a data acquisitions applications standpoint, the MicroBlaze and other soft-core processors offer the advantage of deterministic timing, unlike application processors such as the Rasperry Pi that typically run Linux as an application-scheduling operating system. This lets one precisely control when data is being read from a pin without any jitter, since the FPGA nature of the device lets one rewrite interrupt routines to become truly independent parallel routines that are handled simultaneously. Development boards such as the ARTY also provide prodigious amounts of RAM (256 MB of DDR3L!), significantly more than most microcontroller development boards and provide simple block-design methods to interface them to the soft-core microcontroller. Table 1 compares the capabilities of the sofcore microcontroller described in this article with other common hardware microcontrollers.

The cons

Development environments range from lightweight and sleek to bulky and complicated. The popular development environment used with the ARTY for developing a MicroBlaze soft-core-processor-based system is Vivado, and it is definitely of the 800-lb-gorilla variety. Open Vivado and prepare to be blinded by windows, sidebars and menus. And Vivado is not the only design environment needed; the C code that runs on the MicroBlaze is developed on the Xilinx SDK. For those who enjoy the simplicity of the Arduino integrated development environment, Vivado is a totally different beast.

Compared with the civilized world of microcontrollers, FPGA design definitely has a Wild West feeling.

Moving from the prototype phase to a product with an FPGA is also much more complicated than when using microcontrollers. Prototypes using hardware microcontrollers can often be made using through-hole versions, or relatively simple small outline integrated circuit dual inline package adapters that can be hand soldered. Not so with FPGAs, which have much higher pin counts and pin densities precluding hand-assembly, and which often come in packages such as ball grid arrays that require specialized equipment to wave-solder. FPGAs also require external support circuitry, such as electrically erasable programmable read-only memory, to store the logic design, code, and RAM in separate chips. To produce a PCB with an FPGA and its circuitry typically requires at least four layers.

To get started or seek help implementing functions such as the UART or SPI on the soft-core microcontroller, one must turn to online communities and documentation. The wealth of carefully documented functions and examples that accompany many hardware microcontrollers are simply not present for FPGA development objects such as the ARTY, MicroBlaze, and Vivado. The supplied application programming interface is helpful but often lacks reference examples. The getting-started page for the ARTY is, similarly, a great resource but is littered with "work-in-progress" and "fix-me" tags suggesting what is written in those sections may not be true. As soft-core microcontrollers rise in popularity, this situation will continue to improve, but compared with the civilized world of microcontrollers, FPGA design definitely has a Wild West feeling (see Fig. 2 for one example).

Real-world application

At the Virginia Military Institute, Prof. James Squire offers a course in electro-mechanical design. In this course, senior electrical and computer engineering students are given a real-world engineering consulting project and must interact with an off-campus client to build a device that solves a problem. In the spring of 2016, students in Prof. Squire's Electromechanical Design class at the Virginia Military Institute were asked to design a system to measure the impedance of cells as they grow in a culture well to be used in chemotherapeutic cancer research. It involved creating a front-end graphical user interface (GUI) running on a PC written in C# that communicated to a real-time phase-locked differential amplifier run by a microcontroller. The analog subsystem design and PC/microcontroller interface turned out to be relatively simple; the logic subsystem that permitted analog-to-digital (A/D) acquisition of 18 b of data at a rate of 400 ks/s for up to

TABLE 1. Soft-core versus hardware microcontroller capabilities.

	MICROBLAZE ON ARTY	ARDUINO UNO REV 3	RASPBERRY PI 3
Processor Speed	100 MHz	16 MHz	1.2 GHz
RAM	256 MB DDR3L	2K SRAM	1 GB LPDDR2
Operating System	No	No	Yes

A comparison of a few of the capabilities of the most popular hardware microcontroller development boards with that of the ARTY, a development board for the Artix 7 FPGA. The Raspberry Pi has a higher clock speed and more RAM than either the Arduino or ARTY, but it requires an operating system to run more than one thread, which may not permit timing-critical applications, such as data acquisition, that are intolerant of jitter.

The final phase was by far the most challenging: to increase sampling speed by over three orders of magnitude to 400 ks/s.

10 s at a time turned out to be significantly more complicated (Fig. 3).

We completed the contract in three phases. The first phase simplified the engineering requirements to allow data of 8-b precision to be taken at 100 samples/s for 1 s. This speed enabled the use of a common microcontroller development board, the Teensy by PRJC. The Teensy hosts a 16-b microcontroller with more than enough RAM to hold the data collected at this slow speed, an integrated A/D unit, and onboard USB to allow the upload of collected data. When this was successfully built and tested, the project entered the second phase in which an external A/D converter was interfaced to increase the signal acquisition precision to 18 b. The A/D chosen was capable of up to 400 ks/s speeds, although at this phase, we remained at 100 samples/s. The Teensy remained to control the A/D, store the A/D data, and communicate with the PC to upload the data.

The final phase was by far the most challenging: to increase sampling speed by over three orders of magnitude to 400 ks/s. The A/D was emitting data using a serial interface; 18 b at 400 ks/s requires very tight timing, especially since over half of the time the A/D converter was performing the conversion and, therefore, unable to communicate. This speed required a microcontroller with a very fast clock.

Further, we wanted to embed a sampling timer on the microcontroller to trigger the start of each A/D conversion, but the fastest microcontrollers we could find ran Linux or another scheduling operating system, making it impossible to obtain clock-pulse-accurate jitterless A/D triggering. Another challenge was the raw amount of data: 18 b of data at 400 ks/s over a 10-s experiment generates over 10 MB of data, requiring external RAM.

The solution came with the ARTY development board. The ARTY uses an Artix 7 FPGA and 256 MB of RAM, all on an easy-to-prototype development board. We used the Teensy microcontroller for all non-time-critical management functions including using its USB port to upload the sampled data to the PC. The ARTY was used in the time-critical loop to trigger the A/D conversions, serially clock the data out of the A/D, and store it in its DDR3L RAM. Then it provided the data to the Teensy in chunks using a simple handshaking protocol for the Teensy to send back to the PC for analysis and display (Fig. 4).

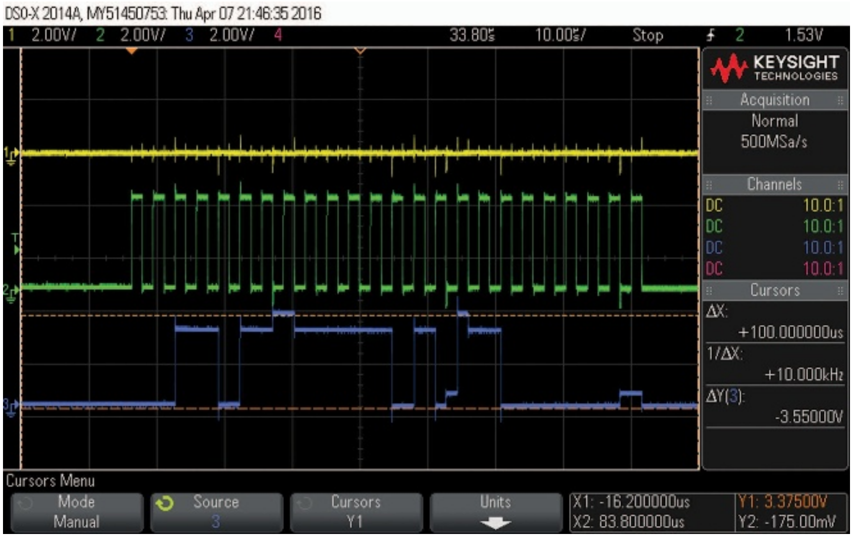

FIG2 The Wild West of FPGA design: A scope screenshot taken while debugging SPI communications errors. The blue channel should be a square wave showing data being sent from an external ADC to the MISO pin on the ARTY. The spikes on the channel suggest that the reference documentation for the software-designed SPI port have reversed the MOSI and MISO pin names, so the FPGA is attempting to (feebly) push data out on its input line. We assume reference documentation to be correct, but this scope capture shows that is not always the case.

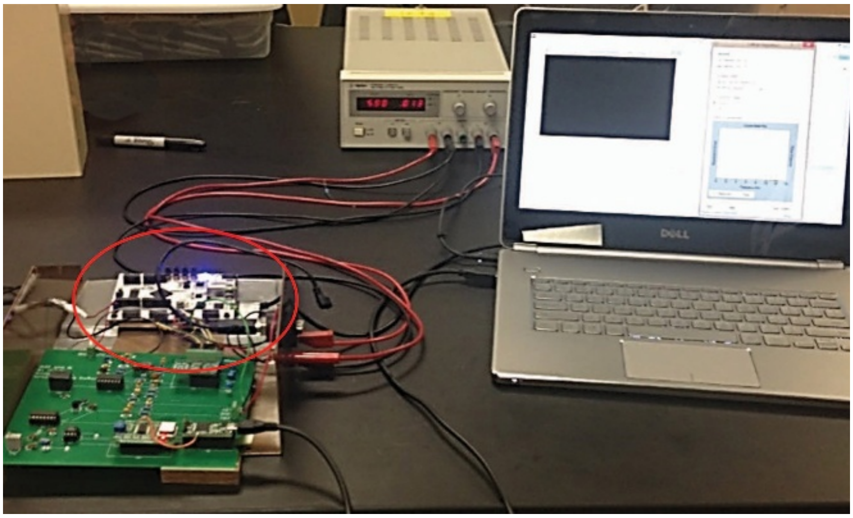

FIG3 The final product delivered to the client's biomedical lab. The product housing is removed to reveal the analog circuitry populated on a custom PCB that is controlled by the ARTY (circled in red). The laptop is running a GUI written in C# to control various data acquisition parameters and analyze and display the collected data.

The team's initial plan was not to use a soft-core microcontroller but rather to design a state machine in the FPGA to trigger the A/D converter, clock out the conversion serially, and store the conversion in successive RAM locations, since these are simple, repetitive operations. This was more complex than we anticipated. Unlike the detailed documentation, tutorials, and example code available for many popular microcontrollers, it quickly became apparent that FPGA programmers form a smaller community, and, therefore, FPGA documentation is less extensive. Vivado is not intuitive to use.

The lead author of this article rode in the back seat with a laptop, using the 10-h ride to clarify comments in the code and add reference documentation, both of which seemed trivial enough to leave for the car ride.

The first problem we attempted to solve in building the state machine was accessing the onboard DDR4 RAM, and after countless hours searching and experimenting, we were still dead in the water. Looking through the ARTY tutorial page, we came across a section that mentioned the soft-core microcontroller named MicroBlaze in a "hello world" tutorial. This simple program gave the basic reference design for the softcore microcontroller, which ultimately laid the foundation to solve all the problems we encountered. It allowed us to change the approach

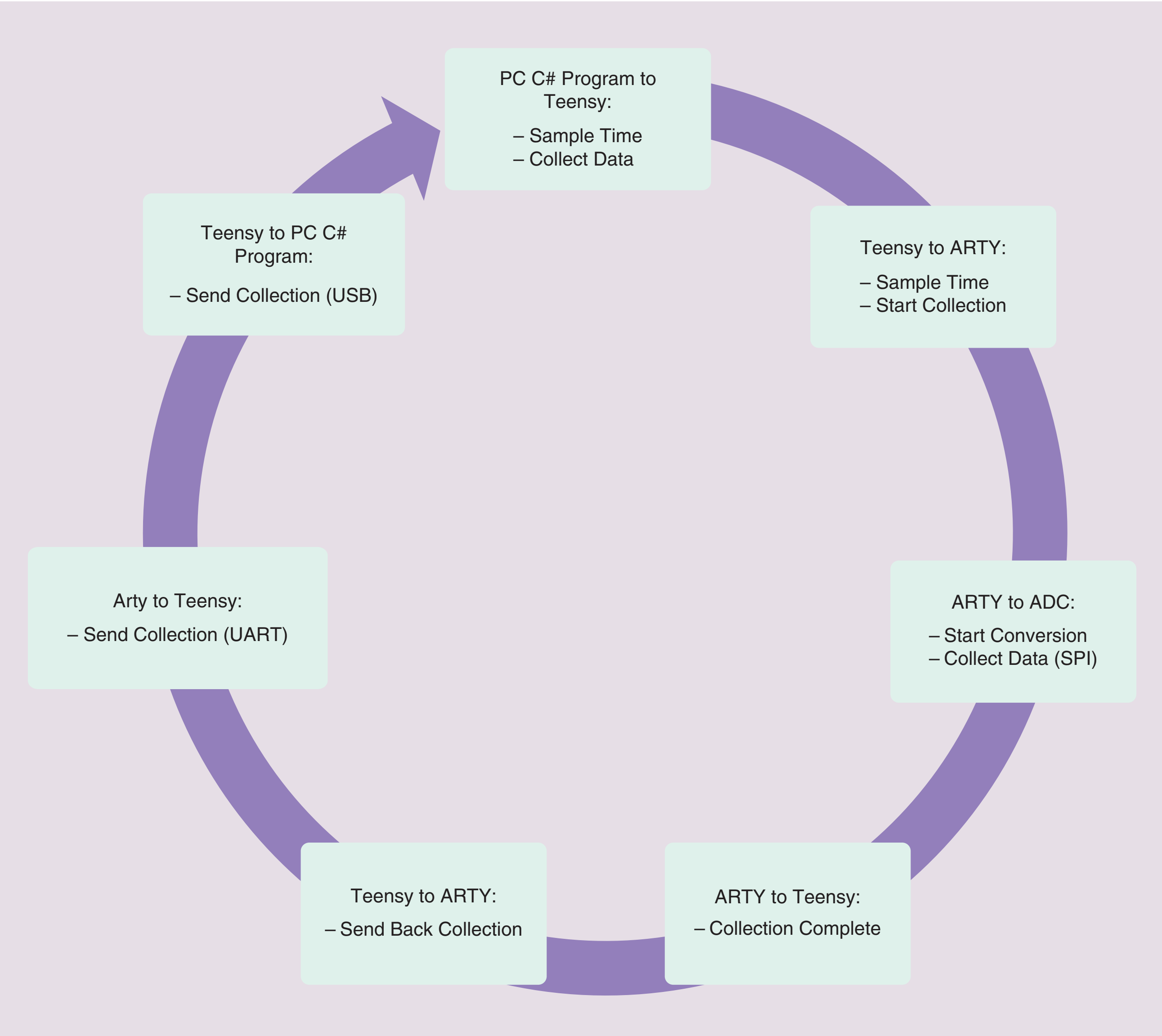

FIG4 Three independently-running computers were used in the project: a PC that ran a C# program to collect user input/graph results, an Arduino-compatible Teensy microcontroller that sent the data over a USB port to the PC, and the ARTY FPGA development board that ran the soft-core microcontroller to collect 18 b of data from the A/D at 400 ks/s speeds with no jitter.

If you need flexibility and performance in your next embedded project, consider a soft-core processor.

of the team from being HDL coders to being traditional C++ coders, a language we had considerably more experience using. The tutorial also showed how to set up the RAM IP Block with the MicroBlaze, which solved the problem of memory interfacing. Further optimization could allow the MicroBlaze to communicate through the ARTY's USB port to the PC, eliminating the Teensy hardware microcontroller entirely.

Murphy's law strikes

Blazing down the highway at 70 mi/h, we headed to Massachusetts to deliver the product to Dr. Anthony English's lab at Western New England University. The lead author of this article rode in the back seat with a laptop, using the 10-h ride to clarify comments in the code and add reference documentation, both of which seemed trivial enough to leave for the car ride. Halfway there, we double-checked to make sure the newly commented code would synthesize (FPGA-speak for *compile*) correctly and were alarmed to find it generating a ton of errors. After some digging, we realized the Vivado package had determined that the car ride over would be a good time to update its core libraries to a new, not fully compatible, version. With a couple of hours left we located the troublesome libraries and began patching the code. As we pulled into the parking lot, I frantically typed our last lines of code and made sure everything verified. It was a little closer than I would have liked to end the semester-long project, but it worked well and Dr. English is currently using it to obtain data (Fig. 5).

If you need flexibility and performance in your next embedded project, consider a soft-core processor. The ARTY provides an excellent introduction—purchase one, read the reference page on the Digilent website, complete a few of their tutorials, and get started on your own design.

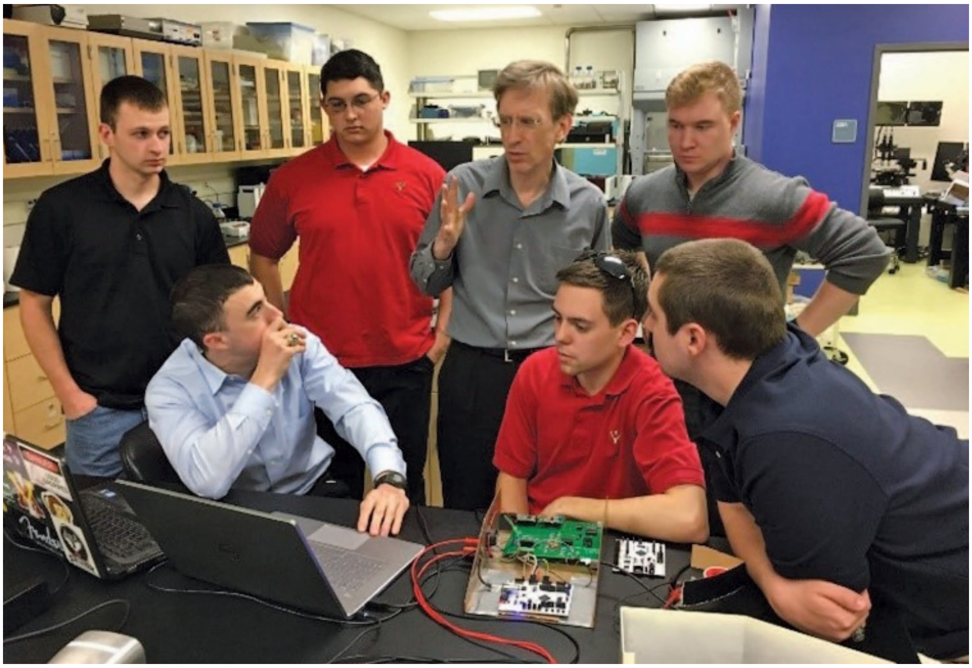

FIG5 After a hair-raising debugging ride to his laboratory, we present our client with the final product and demonstrate that it meets his requirements.

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Smart cities—A road map for development

Sam Musa

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Ever since the industrial revolution, people have been urbanizing at an exponential rate. Hundreds of thousands of new dwellings are currently being built every day. As of 2015, approximately 52% of the world population lives in cities. Every week, there are more than a million new people moving into cities, worldwide.

By 2050, the United Nations (UN) expects that 6 billion people will be living in cities. Since cities consume approximately 70% of the global energy use, the strain on resources and the magnitude of challenges that cities face is phenomenal. As a result, it is imperative to develop solutions that improve the livability of cities while vividly reducing resource consumption.

There is a need for city-wide smart, secure, and resilient transformation. Technological transformation is one option that governments can rely on to mitigate many of the risks and challenges they are facing. Local governments, in general, and chief information officers (CIOs), in

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A technologically resilient city focuses on the economy, society, infrastructure, mobility, strategic planning, and a healthy relationship with all residents.

particular, have to tackle many issues to achieve a successful smart-city government, such as studying communities, engaging residents, allowing access to high-speed Internet, and adopting an open-government philosophy. In short, government officials must develop a road map for building smart cities so that they can leverage and integrate technologies to create real economic opportunities and save lives.

Developing smarter cities

A smart city is a city that engages its citizens and connects its infrastructure electronically. People, processes, and technology are three major elements that shape a smart city. A smart city has the ability to integrate multiple technological solutions, in a secure fashion, to manage its assets, which include, but are not limited to, local departments' information systems, schools, libraries, transportation systems, hospitals, power plants, law enforcement, and other community services. The goal of building a smart city is to improve the quality of life by using technology to improve the efficiency of services and meet residents' needs.

Business drives technology, and large-scale urbanization boosts innovation and new technologies. Technology is inspiring the way city officials interact with their communities and local infrastructure. Through the use of real-time control systems and sensors, data are collected from citizens and then processed in real-time (Poslad, Athen, Zhenchen, and Haibo, 2015). The information and knowledge gathered are keys to tackling inefficiency, which leads to optimizing systems. A smart city offers technological solutions that explain what is happening in the city, how it is evolving, and how to enable a better quality of life for its residents.

The purpose of building smart cities is to make the lives of the residents easier and safer. Technology can be used as an instrument to protect lives and improve services and businesses processes; furthermore, it can protect personally identifiable information (PII) and critical infrastructure, such as transportation, hospitals, power plants, and water-treatment systems. Technology can be used to reduce crime by geographically spotting areas with high crime rates, identifying specific crime patterns, or by detecting the sounds of gunfire and reporting it to law enforcement immediately—and many of these services are achieved by using sensors.

Sensors are small measurement devices that can be integrated with electronics to detect certain sounds, smells, or levels of variations. Sensors can be passive or active. Passive sensors do not necessarily take action; they simply collect data and are used mainly to measure weather conditions, such as wind speed, ground ozone levels, or the sun's ultraviolet index. Active sensor devices use electronics to process data and take action. For example, traffic lights or parking sensors, using electronics, calculate the collected data and then take action based on meeting certain threshold (Bagula, Castelli, and Zennaro, 2015). Raspberry Pi, a credit-card-sized computer, is used in many sensor devices. It uses Linux or Windows 10 Internet of Things (IoT) Core operating systems—Fig. 1 illustrates its components.

The network of physical devices or "things" that work collaboratively by collecting, exchanging and processing data is known as the IoT. Cities remotely control these sensors through wired or wireless networks. The IoT can be used to improve the ability to plan (Gaur, Scotney, Parr, and McClean, 2015). For example, water smart meters can be used to collect information to better understand water issues, such as leaks. City officials can use smart-meter data to target conservation campaigns to areas where water is being abused. Data will also allow officials to focus on improving infrastructure in areas where water leaks are experienced the most.

Attaining resiliency

Transforming cities to be resilient technologically is another method that can be used to protect lives and improve cities. A technologically resilient city focuses on the economy, society, infrastructure, mobility, strategic planning, and a healthy relationship with all residents. Mobility is the ability to perform services using mobile devices from anywhere at any time. Building a sustainable technological infrastructure that provides reliable communications and mobility is one attribute of a resilient city.

Cities face stresses and shocks, such as unemployment, inefficient public transportation, earthquakes, floods, and terrorist and cyberattacks. These stresses and shocks weaken the infrastructure of the city.

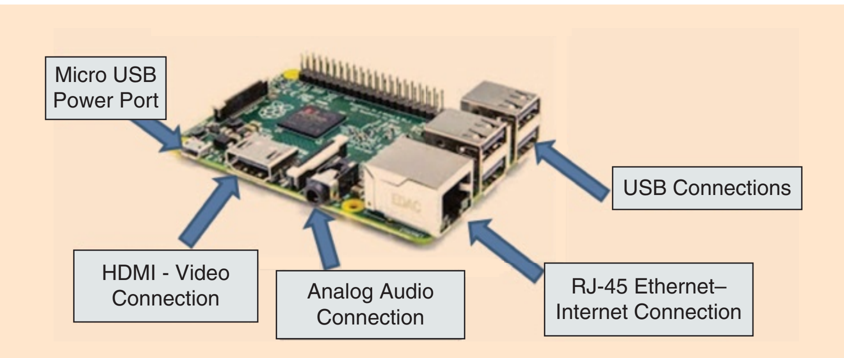

FIG1 The components of a Raspberry Pi computer.

Resilient cities demonstrate many qualities and attributes that allow them to withstand and adapt more readily to shocks and stresses (Bifulco, Tregua, Amitrano, and D'Auria, 2016). Resilient cities can enhance their capability by reflecting on their past experiences and lessons learned to inform safer future decisions and remain protected from stresses and shocks. Emergency preparedness, awareness training, Internet lines redundancy, and data back-up are considered attributes of a resilient city. Figure 2 illustrates the component of a smart city and how technology can be integrated with many sectors to enhance services.

To build a smart and secure city, technology can play a critical role, but it alone is not enough—the city's employees and the community have an equally important role. City officials need to empower the public by engaging them in the decision-making process. Cities need to value their citizens' feedback by encouraging them to participate and contribute to solving problems. Moreover, local citizens must be fully aware of the community challenges and be engaged in shaping the budget allocations and local taxes, among other isues. A 2014 study conducted by the Inter-American Development Bank concluded that citizens' engagement around the budget process led to improvement and satisfaction in creating measurable tax collection (IADB, 2014).

Chief technology officer (CTO) or CIO is typically the title of the individual that leads smart-city initiatives. The role of a city's CIO is to lead its efforts to develop creative and effective technology solutions to address challenges. The CIO is expected to collaborate with residents and elected officials to design effective solutions. These may include the use of technology to increase the capacity of existing infrastructure and services, integrate approaches, and involve citizens through committees and commissions to discuss issues impacting the area. For example, the city of Cupertino, California, created teens, adults, and seniors commissions to address community challenges (Cupertino, 2016). The city CIO should create and foster productive work teams, identify best practices, enhance services delivery, and implement citizens focused initiatives—after all, it's all about the citizens. In short, CIOs must study their communities, know what is needed to meet their citizens' needs, plan and execute related initiatives, and continue improving service delivery methods.

The goal of e-government is to improve service-delivery methods and enhance citizens' involvement in public services.

Electronic government (e-government) involves the use of technology to provide services to the public. The goal of e-government is to improve service-delivery methods and enhance citizens' involvement in public services. E-government can help stimulate economic growth, promote effective natural resource management, and promote social engagement. Local cities and counties are responsible for initiating technological programs to help communities tackle local challenges and improve services. Leadership, represented by mayors, boards of supervisors, and CIOs must be visionary and have the desire, ability, and capability to build a safe and secure smart environment.

Map it

Local governments that are thinking about embarking on smart-city initiatives need to start by developing a roadmap. The top three components for developing a roadmap for a smart city are studying the community, developing a smart-city policy, and engaging the community through e-government and a solid citywide Wi-Fi infrastructure. Figure 3 illustrates the three-step roadmap process.

The first step in establishing a road map for a smart city is to know why there is a need for such an initiative. This can be done by evaluating the city's demographics, including the residents who are the principal stakeholders. People love to live in cities that are convenient, livable, vibrant, and connected, so they can get anywhere whenever they want. Knowing the ages of the citizens,

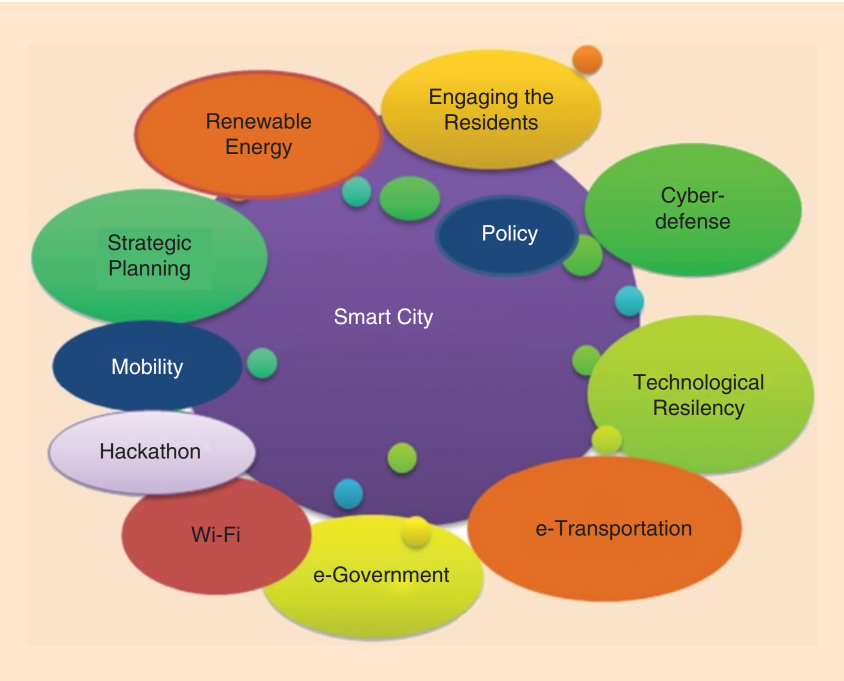

FIG2 The integrated sectors in a smart city.

Free Wi-Fi is a beneficial economic development tool that can be used by tourists and travelers, and it also makes it appealing for residents to be outside in public places, which stimulates the economy.

FIG3 A road map for the development of a smart city.

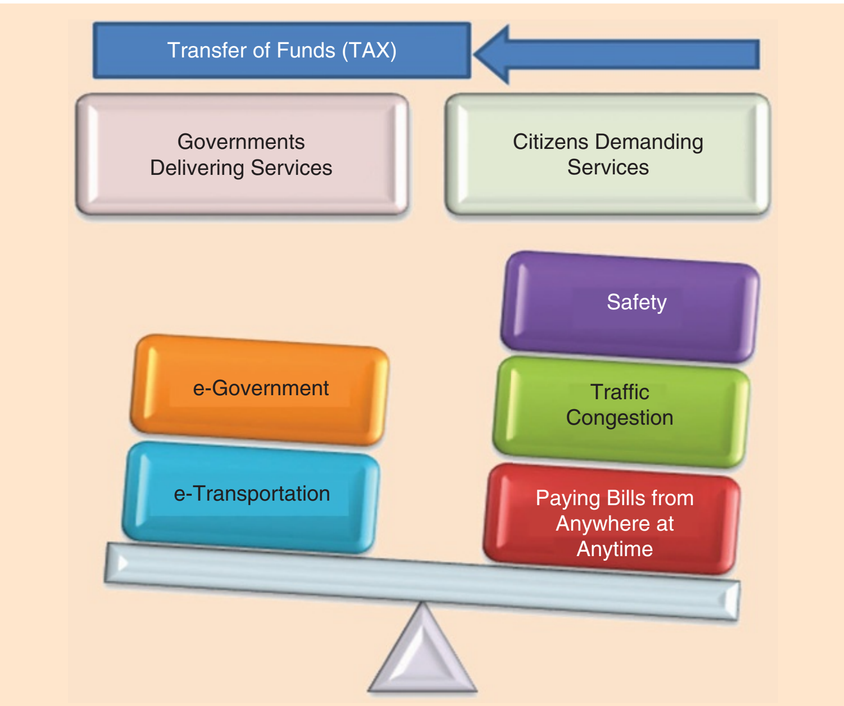

FIG4 The citizens–government relationship.

their educational backgrounds, their hobbies, city attractions, businesses, and the resources of the community are all key steps in getting to know the community and why there is a need to build a smart city.

Geographic information system (GIS) tools are an essential economic development resource that many cities use for planning, analyses, and building lively communities that attract businesses and residents. The government and its citizens function under a supply-and-demand-type relationship; the more services the citizens demand, the more services the government is obligated to deliver—as long as the citizens are willing to pay for them. Figure 4 illustrates the citizens–government relationship, where the citizens' demands for services are kept in balance by the transfer of funds (taxes) from the residents to the government.

The second step in establishing a smart-city road map is by developing a policy that drives the whole initiative. The policy should define the roles, responsibilities, strategies, and objectives of a smart city. A project charter needs to be developed to give the CIO the appropriate power, money, and resources to get the job done. It is the CIO's responsibility to formulate and provide direction on how to use technology to make it easier for citizens and business to interact with the government, save money, and create real economic opportunities.

The third element is engaging citizens through the use of e-government and effective governance, which leads to the increase of efficiency and enhancing the delivery of services. One goal of engaging citizens is to build trust and make them part of the solution. Open data through the use of mobile applications is one way to establish such an engagement. Mobility is a gateway to building a civic engagement, as it allows the public to connect to the city's infrastructure to perform services whenever they want from wherever they are located.

Cities are developing new ways of engaging the public. For example, Palo Alto, California, developed a mobile application that allows its residents to report problems, such as a broken light or water damage (Palo Alto, 2013). In another case, Boston worked with local universities to create applications that allow the public to automatically detect and report the issue to the city. The local city, in return, generates a service request and a notice is sent back to the person who reported the incident, informing him or her that the issue has been resolved.

The city of Cupertino is relying on sports events to initiate civic engagement. The city is hosting the Big Bunny 5K race (3.1 mi) to encourage its residents to be healthy, positive, and connected (Cupertino, 2016). It is using the money the event raises for charities that focus on bringing clean water worldwide. Such an engagement can be used to build trust with the public. By increasing engagement, the city is creating an opportunity for the residents to get to know each other. This is a brilliant way to get people to start caring about each other and their city.

Another method to engage citizens is by granting access to high-speed Internet and constructing city-wide Wi-Fi wireless infrastructure. Affordable and reliable Internet connectivity needs to be available and accessible from anywhere in the city. Open Wi-Fi has economic, social, environmental, educational, and safety benefits. Free Wi-Fi is a beneficial economic development tool that can be used by tourists and travelers, and it also makes it appealing for residents to be outside in public places, which stimulates the economy. Furthermore, it benefits emergency services as Wi-Fi networks are used to aid rescue workers. Wi-Fi is even used by federal agencies for emergency and border patrol purposes. For example, the U.S. Department of Homeland Security funded a free Wi-Fi service along Interstate 19 in Arizona, which is used by the community and federal agencies for emergency services. Open Wi-Fi is simply a win-win solution, as it supports the growth of new businesses, virtual learning, and mobile entertainment. In addition, the city can make use of its wide wireless infrastructure to build the IoT.

Government officials must build a coalition to collaborate, leverage, and integrate technologies to create real economic opportunities by fostering a city-wide, smart, secure, and resilient transformation.

Conclusion

Cities and counties face many challenges and risks, such as unemployment, poverty, traffic congestion, high crime rates, cyberattacks, and slow bureaucratic systems for processing business transactions. People, processes, and technology are three pillars of smart-city initiatives that can be utilized to alleviate such a challenge.

Cities and counties should study their communities, create policies, and implement technological solutions to meet the needs of their local communities. Local, state, and federal governments must be innovative and develop a road map to address and provide solutions to mitigate risks and challenges to create a sustainable future for their citizens.

Digital transformation is one option that governments can rely on to overcome many of these challenges; other options may include adopting e-government, engaging residents, and building resilient cities. Government officials must build a coalition to collaborate, leverage, and integrate technologies to create real economic opportunities by fostering a city-wide, smart, secure, and resilient transformation.

Read more about it

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Sounding off on industrial alarm systems

Ahmad W. Al-Dabbagh and Tongwen Chen

The area of alarm systems is experiencing growing interest in the research community. It is considered interdisciplinary, as it spans several areas, such as process control and automation systems, data mining and analytics, and human factors. The objective of this article is to provide a general introduction of alarm systems and some associated challenges and research directions.

An alarm system is a critical part of an industrial control system. It provides information regarding the behavior of the controlled process. Human operators that run the controlled process can utilize the provided information to make corrective actions. The accuracy, timeliness, and presentation of the information in an alarm system plays an important role in the safety and performance of an industrial control system.

An example process system

Consider a simple process system depicted in Fig. 1. A control system to regulate the behavior of the process may consist of the following components:

- Actuators: devices that implement corrective actions; for example, the inflow pump (P_1) and the outflow valve (V_1).
- Sensors: devices that provide measurements; for example, measuring the flow rate after the inflow pump (F_1), the level of the tank (L_1), and the flow rate after the outflow valve (F_2).
- Controllers: devices that perform advanced decision making; for example, a controller utilizes the values of the sensors to generate regulating commands for the actuators, such as a programmable logic controller. A controller may regulate the status of pump P_1 and the position of valve V_1 to maintain the level of the tank (i.e., measured by L_1) within a specified operating range (e.g., 20–80%).
- Operator interface systems: devices that allow monitoring and manual control of the controlled process, such as a human–machine interface or supervisory control and data acquisition systems. The systems may also have the capability of storing information for future use (e.g., historization in a database). For example, an operator interface system may allow an operator to manually control the devices to regulate the level of the tank, monitor the process

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and its devices, and store the information for future use.

- Communication networks: the devices and medium that regulate data transmission between the devices of the controlled process. For example, communication networks may transfer information between the controller system and the operator interface system as well as sensors and actuators.

Further, depending on the control system utilized to regulate a process system, additional components may also be added, such as systems for data historization and reporting, switches, and other devices.

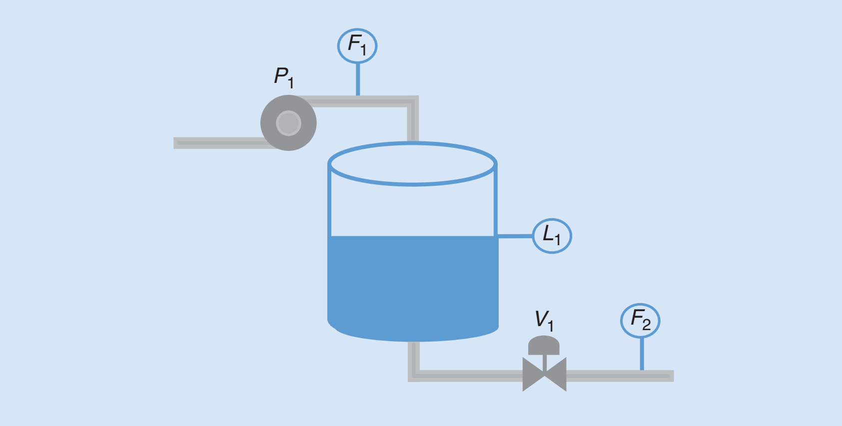

FIG1 An example process system consisting of several devices.

A look at alarm signals

An operator interface system can have a comprehensive graphical representation of a controlled process and its devices. It presents the behavior of the devices to the operators. An alarm system can be coupled with an operator interface system to present information on faulty/abnormal operation of the process and its devices based on alarm signals. For example, for the controlled process depicted in Fig. 1, example alarm signals are summarized in Table 1.

For a process system, alarm signals can be generated in the respective controller system based on the information received from the sensors and actuators as well as from other relevant devices. Consider the process signal depicted in Fig. 2.

The process signal can represent any measured signal of interest (e.g., level measured by L_1, flow rate measured by F_1 or F_2 in Fig. 1). The process signal has an associated alarm set point/trip point, configured as γ. When the process signal exceeds the alarm set point (namely, at time t_1), the process signal is considered to be in abnormal operation (e.g., high level or high flow rate). At this time, the respective alarm signal can change from the clear/normal state (0) to the alarm state (1) instantly or after a specified period of continuous abnormal operation (at time t_2). This period of time is referred to as *on-delay*. After the abnormal operation is resolved (at time t_3), the alarm signal can change from the alarm state to the clear state instantly or after a specified period of continuous normal operation (at time t_4). This period of time is referred to as *off-delay*.

Furthermore, instead of the on-delay and off-delay times, deadbands can be configured such that the change in the alarm signal occurs after the process signal is continuously higher or lower than a specified margin. For example, the process signal is higher or lower than the alarm set point by a given percentage. In addition, the process signal depicted in Fig. 2 is an analog signal. For a digital signal with two binary states (e.g., feedback from a switch with values 0 or 1), an alarm can be configured based on the occurrence of one of the two states (e.g., when the switch is open, an alarm occurs).

A look at alarm displays

In an operator interface system, the state of an alarm signal is presented (e.g., when the alarm signal changes from the clear to the alarm state). The presentation can be achieved using text messages, graphical displays, or audible sounds. This allows operators to monitor and control the process. For example, in the event of a high-level alarm on the tank of the process depicted in Fig. 1, an operator may choose to open the outflow valve V_1, and/or to stop the inflow pump P_1. After resolving the faulty/abnormal operation, the presentation of the alarm is no longer necessary.

TABLE 1. The types of alarms for the example process system.

DEVICE	ALARM	DESCRIPTION
Valve	Failed-to-Open, Failed-to-Close, or Failed-to-Actuate	A command is issued to open, close, or actuate (e.g., set point for opening position), respectively, and the valve does not follow the command.
Pump	Failed-to-Run, Failed-to-Stop, or Failed-to-Actuate	A command is issued to run, stop, or actuate (e.g., set point for speed) and the pump does not follow the command.
Level	Low and Low Low High and High High	The level is below specified low and low low set points, respectively. The level is above specified high and high high set points, respectively.
Flow	High and High High	The flow rate is above specified high and high high set points, respectively.
Communication	Failed-to-Communicate	Communication is lost with the respective device.

An alarm system is used to allow operators to monitor the behavior of the process and its devices, and additional information may be provided to facilitate a more efficient response to faulty/abnormal situations.

However, the alarm system may still present the alarm until it is acknowledged by the operator (at time t_5 in Fig. 2).

An alarm system is used to allow operators to monitor the behavior of the process and its devices, and additional information may be provided to facilitate a more efficient response to faulty/abnormal situations. The additional information may include: the time of the occurrence of the alarm, the location of the respective device (e.g., plant, area, and unit numbers), and the priority of the alarm. The priority can represent the severity of the alarm and the respective impact on the process (e.g., low, high, and emergency). Consider the process system in Fig. 1. An example of a list of alarms is presented in Fig. 3.

In the list, the operators have adequate information to assess and troubleshoot the process faulty/abnormal operation. More specifically, the sensor L_1 of the tank, which belongs to unit 1 of plant 1, had a communication alarm of high priority, and it was acknowledged at 13:21:01 on 20 March 2016. The time may also be configured as the time of the occurrence of the alarm. Shortly after, between the times 13:58:02–14:12:04, a series of alarms occurred. The valve V_1 failed to open and the flow rate measured by sensor F_1 was high. Consequently, with a high inflow into the tank and no outflow, an overfilling of tank 1 took place. Therefore, a high alarm and, later, a high high alarm were displayed with priorities high and emergency, respectively. The entire row of the high high alarm is highlighted in red in Fig. 3 to emphasize the criticality of the event.

Alarm signals and systems may be configured differently from one application to another. This depends on several factors, such as the designer of the operator interface system and the adopted standards. For example, in an alarm system, operator acknowledgments may only be effective after resolving the faulty/abnormal operation. However, an alarm system can also be configured such that acknowledgments are effective at any time after the occurrence of the faulty/abnormal operation.

For example, for the process and alarm signals depicted in Fig. 2, if an operator acknowledges the alarm between times t_2 and t_4, the alarm will no longer be presented on the operator interface system after time t_4. Furthermore, on-delay and off-delay timers as well as deadbands may or may not be configured for alarm signals, For the process and alarm signals depicted in Fig. 2, the alarm is presented at the time of change from the clear state to the alarm state at time t_1 and is no longer presented after the time of change from the alarm state to the clear state at time t_3. Also, an alarm system may allow operators to perform other actions on presented alarms, such as ignoring alarms, or removing alarms from the displayed list.

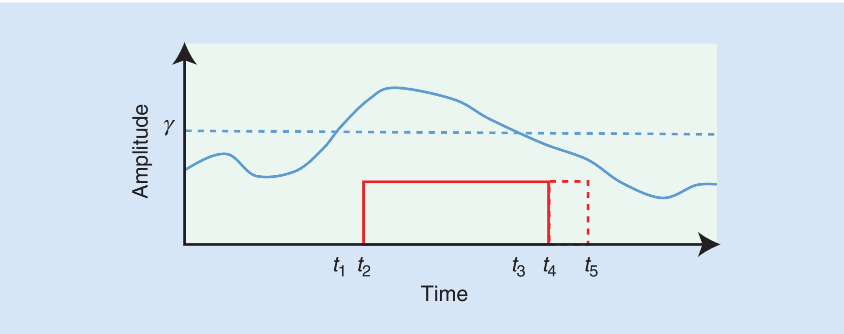

FIG2 The example process signal (solid blue line), alarm set point (dashed blue line), alarm signal (solid red line), and alarm signal latched until operator acknowledgment (dashed red line).

Challenges and potential research directions

Figure 1 is a simple process system consisting of a few devices. In large-scale industrial applications, process

Alarm	Description	Location	Priority	Status	Time
L1-HiHi	Level 1 High High Alarm	P1-U1-Tank1	Emergency	Active	14:12:04 20-03-2016
L1-Hi	Level 1 High Alarm	P1-U1-Tank1	High	Active	14:01:13 20-03-2016
F1-Hi	Flow Sensor 1 High Alarm	P1-U1-Tank1	Medium	Active	13:58:12 20-03-2016
V1-Open	Valve 1 Failed to Open Alarm	P1-U1-Tank1	Medium	Active	13:58:02 20-03-2016
L1-Comm	Level 1 Communication Alarm	P1-U1-Tank1	High	Ack.	13:21:01 20-03-2016

FIG3 An example display list of alarms. P1: plant 1; U1: unit 1.

systems can include a large number of devices. Thus, a significant amount of information may need to be presented on the operator interface system. This necessitates operators to monitor and comprehend what can become an overwhelming amount of information prior to making manual control actions in the process.

Given the criticality of the safety and performance of a control system, an alarm system is required to be optimized such that it is easy for operators to monitor and make control decisions and actions. As a result, research in the area of alarm systems is necessary to address several aspects of improving such systems. Some challenges and potential research directions in the alarm systems area are introduced and summarized next, and further details on the topics and related research work can be found in the literature.

Alarm floods

A large number of alarms can be displayed in a short period of time on the operator interface system. This is referred to as an *alarm flood*. It can lead to having a long list of alarms that an operator is required to address, and it can cause distraction and confusion. Thus, it may impact the time and decisions for taking action in the process. Potential research directions to address alarm floods include the studying of the sequence of occurrence of alarms in a flood, where identification of similar sequences can facilitate design efforts of alarm systems and the configuration of alarm signals, the identification of root cause alarms that lead to a large number of alarms to assist operators to focus on more critical alarms, and optimized display of the alarms such that more critical alarms are displayed in a more visible fashion.

Visualization methods

Visualization and human factors are important aspects of designing alarm and operator interface systems. With a large amount of information displayed on the operator interface system, it is easy for an operator to miss important information needed in making critical control decisions and actions.

As such, the display of the information should be both concise and efficient. Potential research directions to address the visualization and human factors in the design of an alarm system include 1) the optimized display of alarms that require more immediate attention to assist operators in resolving more critical faulty/abnormal operations and to mitigate more consequential alarms and 2) the optimized reporting of historical alarms and the corresponding operator actions to assist in the design of enhanced alarm systems and operator procedures.

It is useful to incorporate methods in the configuration of the alarm signals (e.g., on-delay and off-delay timers) to reduce and eliminate fleeting and chattering alarms.

Fleeting and chattering alarms

The configuration of alarms displayed on an operator interface system can impact the number of alarms that operators are required to address. This introduces an additional and unnecessary burden in addressing alarms. Consider the process and alarm signals depicted in Fig. 4 (with no on-delay and off-delay times).

An alarm that unrepeatably appears for a short period of time, such as in the interval between t_1 and t_2, is referred to as a *fleeting* alarm. An alarm that repeatedly appears for a short period of time, such as in the interval between t_3 and t_7, is referred to as a *chattering* alarm. The fleeting and chattering alarms are considered *nuisance* alarms. Given a large number of alarms, including those that are fleeting and chattering, an operator is required to monitor and comprehend a large amount of information. So, it is useful to incorporate methods in the configuration of the alarm signals (e.g., on-delay and off-delay timers) to reduce and eliminate fleeting and chattering alarms.

Potential research directions to address fleeting and chattering alarms include the configuration of on-delay and off-delay timers with optimal values to reduce nuisance alarms and to assist in improving the efficiency of an alarm system; the configuration of filters and deadbands in an alarm system to assist in the reduction and elimination of fleeting and chattering alarms; and the analysis of fleeting and chattering alarms to provide insight into the root causes for the occurrence of the alarms, such as devices that require maintenance (e.g., tuning and troubleshooting) and alarm signals that require reconfiguration.

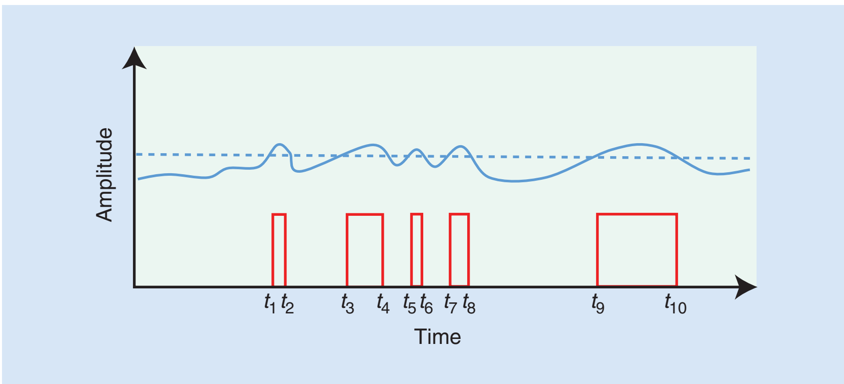

FIG4 The process signal (solid blue line), alarm set point (dashed blue line), and fleeting and chattering alarm signals (solid red lines).

Configuration of alarm set points

The set points used for the change of alarm states (e.g., the dashed blue lines in Figs. 2 and 4) are static and may not be optimal. This may cause unnecessary alarms to be displayed and lead to a waste of efforts and resources in addressing alarms. Potential research directions to address the configuration of alarm set points include the tuning of the alarm set points to achieve optimal values, the configuration of dynamic set points (time-/event-varying) to achieve adaptive set points, and the configuration of alarms based on multiple process signals, in contrast to alarms based on one process signal, such as those in Figs. 2 and 4.

Root causes and consequential alarms

The number of alarms that are displayed on an operator interface system can be significant and overwhelming to address. In addition, alarms can be generated based on a fault/abnormality that propagates in the process. Thus, the analysis, reduction, and optimal presentation of alarms can assist in providing a more efficient alarm system. Potential research directions to address root causes and consequential alarms include the classification of root cause alarms that lead to the display of a large number of alarms to assist operators in focusing on specific tasks, the analysis of cause and effect relations between alarms, and the prediction of future alarms to anticipate and mitigate critical alarms.

Operator actions

An operator interface system may have the ability of storing actions taken by operators to address historical alarms (e.g., changing set points, manually controlling devices, and acknowledgments). The stored actions can be analyzed to optimize future response procedures. Potential research directions to analyze the operator response to alarms include 1) the development of a model, potentially dynamic and time-/event-varying, to capture the response patterns of operators in addressing historical alarms and 2) the analysis of the response time of operators to historical alarms to facilitate the determination of optimal response times to address and eliminate future alarms.

Conclusion

A control system consists of several components that are jointly used to control a process. These components include sensors, actuators, controllers, communication networks, and operator interface systems. In addition, human operators can monitor and manually control the process using an operator interface system. An alarm system plays a critical role in providing operators necessary information to control the process, and the improvement of such systems can provide a major benefit to industrial applications.

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Read more about it

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Emerging smart methodologies for on-road electrical energy harvesting

Twinkle Thobias, Gibin Mathew Padayattil, and Gopakumar P.

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Rising concerns of global warming and diminishing fossil fuels are triggering research toward alternative renewable-energy-based methods for electricity generation. These alternate methods are preferred to be implemented in the form of distributed generation rather than conventional centralized generation. The benefits of distributed power generation have been widely accepted by researchers and industrialists in recent years. Numerous research pertain to the area of distributed generation that utilize all possible forms of eco-friendly green energy.

One of the emerging methods is electricity harvesting from on-road speed breakers. These methods rely on effective utilization of kinetic energy stored in moving vehicles for electricity generation. Speed breakers adopted for generating electricity from the kinetic energy of moving vehicles are commonly referred to as *power humps*. Electricity generation in power humps is achieved using either mechanical systems or semiconductor technology.

The generated power from power humps can be used for general-purpose applications such as street lights, traffic signals after power conditioning, and regulation. The generated electrical voltage profile can be enhanced by connecting multiple power humps in series. The generated power can be stored in capacitors or other energy storage systems for future use. Mechanical system and semiconductor-technology-based power humps are explored in the following section.

On-road power generation methods using speed breakers

As presented in the preceding section, major on-road power generation techniques can be broadly sub-divided into two categories: those based on mechanical systems or those based on semiconductor technology. Both methods can also be categorized into numerous streams. However, the major streams under mechanical-system-based power humps and semiconductor-technology-based power humps are included in Fig. 1. These methods are further detailed with block diagrams, principles of operation, and advantages and disadvantages in the following subsections.

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Roller-mechanism-based power hump

The roller-mechanism-based power hump consists of a cylindrical roller mounted between speed breaker terminals in such a way that when a vehicle passes over the speed breaker, the roller is rotated. Some form of grip or slanted surface is installed at the sides of the roller so that the vehicle can easily move on the roller. The roller end is connected to an electrical generator (e.g., dynamo) shaft though chain drive or gear arrangement. Electrical energy is extracted from terminals of the generator and can be fed to storage systems or local loads through power conditioning and regulating circuits. The principle of operation of roller-mechanism-based power humps is included in Fig. 2.

The maximum electric energy that can be extracted from the system depends on the roller size and generator capacity. Unlike other power humps, the weight of the vehicle has a minor impact on the electrical power generated. A few hundred watts of power can be easily generated using a small generator and roller arrangement. The roller mechanism may not support high-inertia generators, as such generators make the roller difficult to rotate. Since high-power generators offer higher inertia, roller-mechanism-based power humps are limited to medium-power generation in the range of a few kilowatts (average).

The total installation cost of the system is less than other power hump systems. The roller mechanism can be easily implemented, even without digging up the road (by keeping the generator and associated circuits on the road). These power humps may become impaired when heavy vehicles pass over and, as a result, they often are utilized in areas free of heavy vehicles such as shopping mall parking lots.

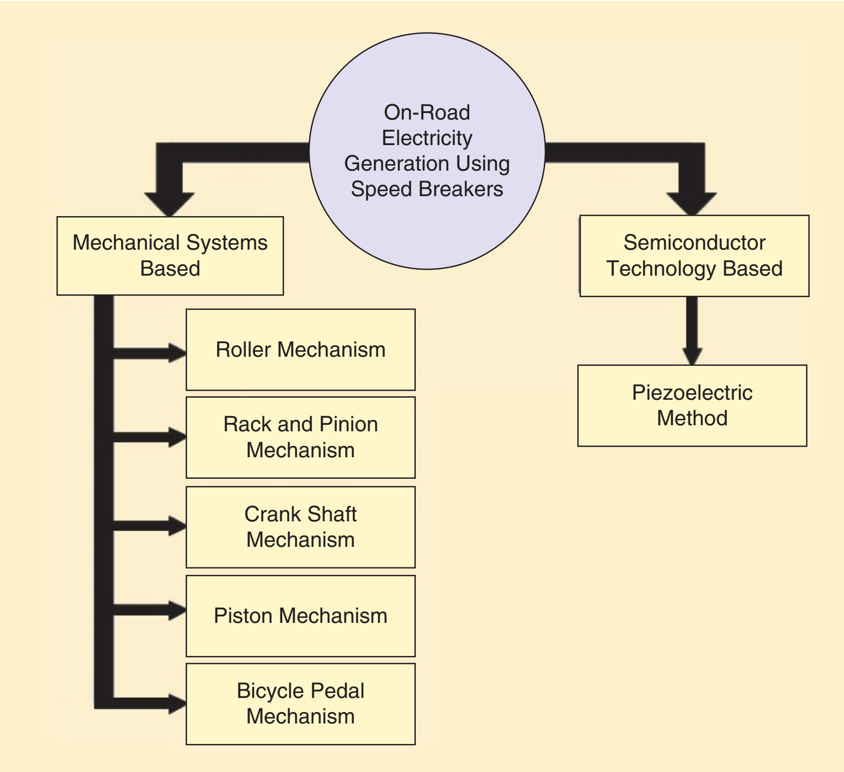

FIG1 The classification of on-road speed-breaker-based electricity generation methods.

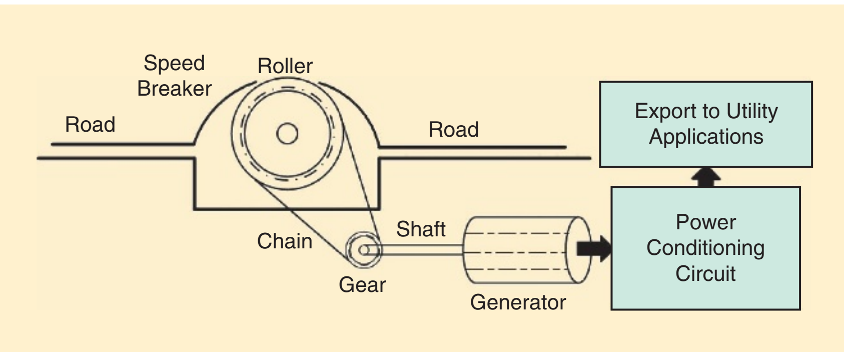

FIG2 The principle of operation of roller-mechanism-based power hump (with the generator kept under the road).

Rack-and-pinion-mechanism-based power hump

A rack and pinion is a type of actuator that converts rotational motion into linear motion, or vice versa. A pinion is a circular gear with teeth, and a rack is a linear bar with teeth. Both rack and pinion are coupled together so that linear motion applied to the rack causes a relative rotational motion in the pinion (and vice versa).

In the rack-and-pinion-based power hump, the mechanism is developed under a dome-like structure, which acts as a speed breaker. The pinion is mechanically coupled to the shaft of an electrical generator. When a vehicle passes over the dome, the dome moves downward due to the vehicle's weight. As the rack is attached to the bottom of the dome, the rack also moves downward with the dome. Once the vehicle passes over, due to tension in spring, the dome moves upward and settles in its original position. During this time, the rack also moves upward with the dome. The rack-and-pinion mechanism converts this reciprocating motion into rotary motion, which enables the electricity generator shaft to rotate. Electrical energy is extracted from terminals of the generator and can be fed to storage systems or local loads. The principle of operation of a rack-and-pinion-mechanism-based power hump is shown in Fig. 3.

The maximum electrical energy that can be extracted from the system depends on the rack-and-pinion mechanism and the capacity of the installed generator. Unlike roller power humps, the amount of generated electrical energy from a rack and-pinion-mechanism-based power hump is a factor of both the weight and velocity of the vehicle. Since the weight and velocity of the vehicle are utilized for generator shaft rotation, high-power generators (that possess higher inertia) can be adopted. This facilitates higher electrical power generation compared to roller-mechanism-based power humps. With a simple rack-and-pinion arrangement, vehicles weighing a few hundred kilograms can facilitate the generation of a few kilowatts of average power. The total installation cost of the system is greater than roller-mechanism-based power humps. Rack-and-pinion-mechanism-based power humps are immune to heavy vehicles and can be installed on national highways.

In the rack-and-pinion-based power hump, the mechanism is developed under a dome-like structure, which acts as a speed breaker.

Crank-shaft-mechanism-based power hump

The crank-shaft mechanism for electricity generation from speed breakers is similar to that of rack-and-pinion-mechanism-based power humps. In contrast to the rack-and-pinion arrangement in the latter, the former consists of a metal shaft and crank wheel. The metal shaft is connected at the bottom of the dome, which acts as a speed breaker. The metal shaft is joined to the crank wheel, which is coupled to the shaft of an electric generator. When the vehicle passes over it, the dome moves downward, and the linear motion of shaft is converted into rotary motion by the crank wheel. The electric generator and the crank wheel can be coupled in their shafts through a gear mechanism. As a result, when the dome moves, the shaft of the generator rotates and electrical energy is generated. A spring arrangement is necessary to keep the dome upright and place it in its original position after the vehicle has passed. The principle of operation of a crank-shaft-mechanism-based power hump is included in Fig. 4.

The maximum electric energy that can be extracted from the system depends on the crank shaft mechanism and the capacity of the installed generator. Similar to rack-and-pinion-mechanism-based power humps, the amount of generated electrical energy from crank-shaft-mechanism-based power humps is a factor of both weight and velocity of the vehicle. So, this system also facilitates higher electrical power generation compared to roller-mechanism-based power humps. Vehicles weighing a few hundred kilograms can generate a few kilowatts of electrical power (average). The presence of the rotating crank requires the system to necessitate a larger floor area and calls for higher maintenance for smooth operation. The system is immune to heavy vehicles and thus can be installed on national highways.

Piston-mechanism-based power hump

In this mechanism, similar to the crank-shaft mechanism, a dome is used as speed breaker. Under the dome, a piston is connected. The other end of the piston is kept inside a cylinder with fluid or air. A turbine is located inside the cylinder, and the turbine is coupled to an electricity generator. When the dome moves downward (when a vehicle is passing over

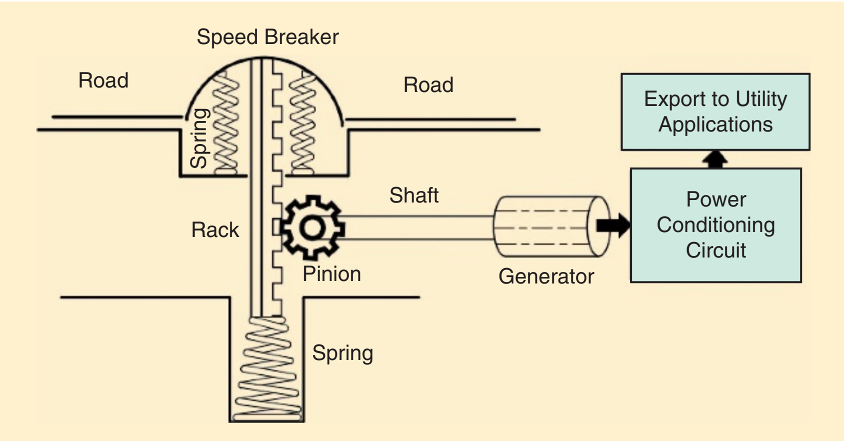

FIG3 The principle of operation of a rack-and-pinion-mechanism-based power hump.

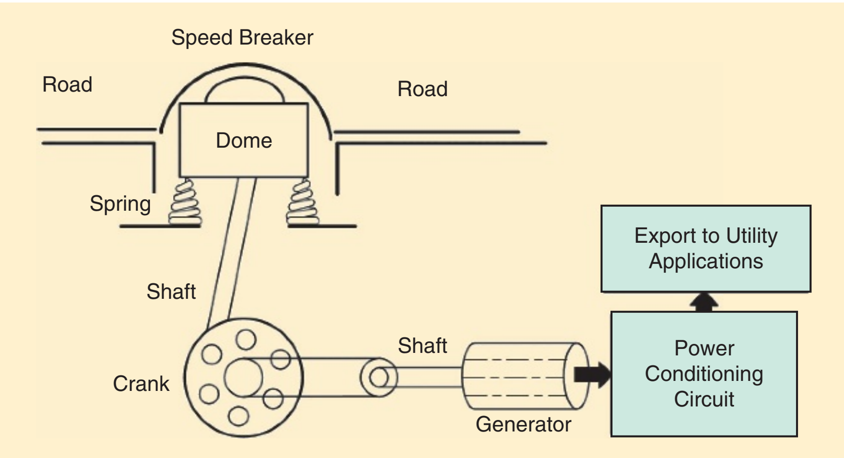

FIG4 The principle of operation of a crank-shaft-mechanism-based power hump.

it), the piston moves down and results in the movement of fluid or air inside the cylinder. This movement of fluid or air makes the turbine rotate and, from this turbine rotation, electrical energy is generated. The principle of operation of piston-mechanism-based power hump is shown in Fig. 5.

The maximum electrical energy that can be extracted from this system depends on the pressure of the fluid/air and the capacity of the installed generator. The amount of generated electrical energy from the system is a factor of both the weight and velocity of the vehicle. However, heavy generators cannot be utilized in the system due to limitations in the quantity and pressure of fluid/air pumped to the turbine. As a result, an average power of a few hundreds of watts of electrical power can be generated using the system when a vehicle weighing a few hundred kilogram passes over. The requirement of a circulating pump, turbine, and concealed chamber make the system complex and costly. Also, negative pressure present in the concealed chamber after the downward movement of the dome may result in a longer time period for the return movement of the dome.

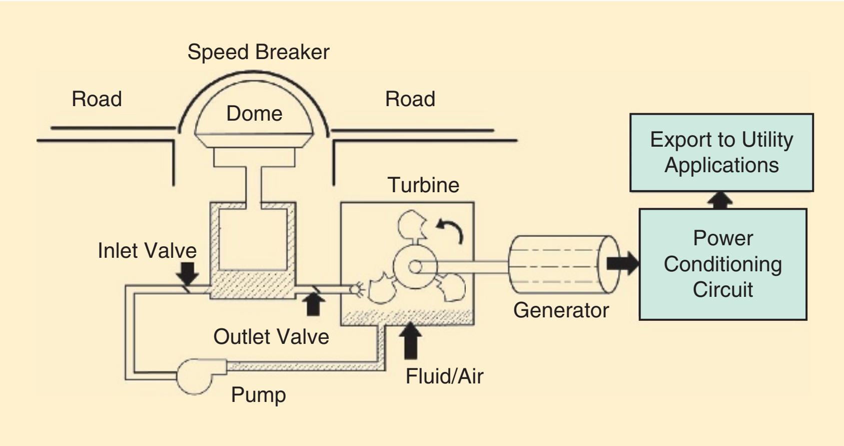

FIG5 The principle of operation of a piston-mechanism-based power hump.

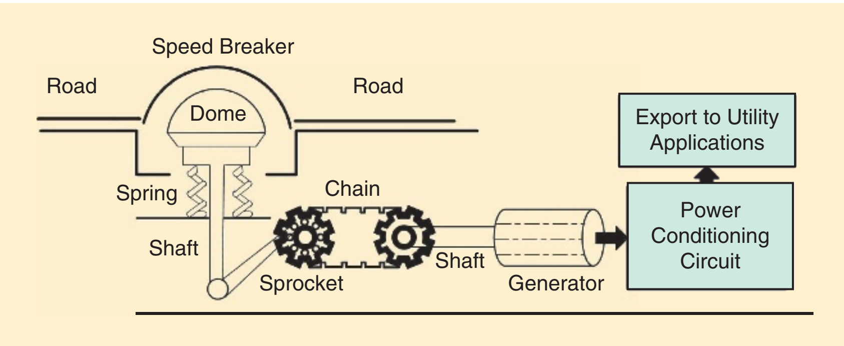

FIG6 A bicycle-pedal-mechanism-based power hump.

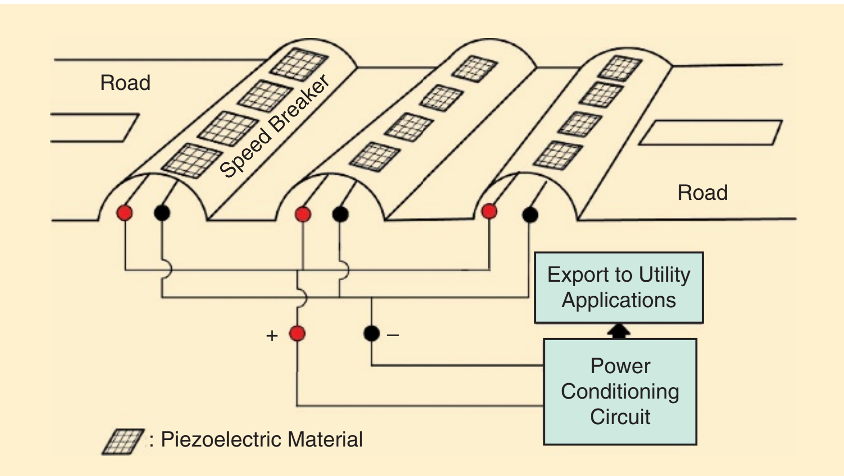

FIG7 The principle of operation of a piezoelectric-based power hump.

Bicycle-pedal-mechanism-based power hump

Similar to the aforementioned mechanisms, the bicycle-pedal-mechanism-based power hump consists of a dome that acts as a speed breaker. Under the dome, a pedal-wheel (sprocket) mechanism similar to that of a bicycle is mounted. When the vehicle passes over the dome (speed breaker), the sprocket rotates. The sprocket is coupled to the shaft of an electric generator. Then, when a vehicle passes over the dome, the sprocket rotates, as does the shaft of the electric generator. When shaft rotates, electricity is generated. The principle of operation of the bicycle-pedal-mechanism-based power hump is included in Fig. 6.

The maximum electrical energy that can be extracted from the system depends on the shaft and sprocket mechanism as well as the capacity of the installed generator. The amount of generated electrical energy from the system is a factor of both the weight and velocity of the vehicle. Since the weight of the vehicle is utilized for generator shaft rotation, high-power generators (that possess higher inertia) can be adopted. With a simple shaft and sprocket arrangement, vehicles weighing a few hundred kilograms can facilitate the generation of a few kilowatts of average power. The requirement of a larger number of mechanical components make the system less efficient compared to others. However, all of the mechanical parts required to implement the system are simple and readily available. Regular inspection is necessary for the effective functioning of the system. Similar to rack-and-pinion-mechanism-based power humps, these power humps are also immune to heavy vehicles and thus can be installed on national highways.

Piezoelectric-method-based power hump

In this method, electricity is generated directly without the aid of mechanical movements. The speed breaker is covered with piezoelectric materials, which generate electrical voltage when subjected to mechanical stress (such as vibration or load). So, when the speed breaker is covered with piezoelectric material, electricity is generated when the vehicle passes over it. This method of power generation is easier to implement when compared to mechanical approaches for power humps. The principle of operation of a piezoelectric-method-based power hump is shown in Fig. 7.

TABLE 1. The advantages and disadvantages of various power-hump mechanisms.

SL. NO.	MECHANISM	ADVANTAGES	DISADVANTAGES
1)	Roller mechanism	1) Lesser requirements of mechanical parts.	1) Larger floor area is required when compared to a rack-and-pinion-mechanism-based power hump.
		2) Direct rotational movement can be obtained.	2) Susceptible to damage under heavy vehicles, as roller is mounted on two end points.
		3) It can be implemented on the surface of the road without damaging it.	3) Generated electrical energy largely depends on the velocity of vehicle that passes over it.
		4) Does not require any spring arrangement (in contrast to other mechanical-based systems).	4) The weight of the vehicle has a minor impact on the electricity generated.
2)	Rack and pinion	1) Rack-and-pinion assembly provides mounting convenience.	1) Since the mechanism is kept under the road, installation requires the road to be dug up.
		2) Generated electrical energy is proportional to both the weight and velocity of the vehicle that passes over it.	2) Require more mechanical parts, hence higher mechanical losses.
		3) Lesser requirement of floor area.	3) Requires reciprocating to rotatory translation.
		4) Immune against heavy vehicles.	4) Requires heavy spring arrangement.
3)	Crank shaft	1) Since crank-shaft is mounted on bearings, balancing problem does not occur.	1) Similar to a rack-and-pinion system, installation requires the road to be dug up.
		2) Compared to rack-and-pinion method, a smaller spring is sufficient.	2) Mechanical vibrations can damage the bearings.
		3) Spring is so connected that it facilitates upward movement of the crank shaft after a vehicle passes over it, thus delivering a better power generation.	
		4) Generated electrical energy is a factor of both the weight and velocity of the vehicle that passes over it.	
		5) Immune against heavy vehicles.	
4)	Piston mechanism	1) Lesser mechanical parts required compared to other mechanical-system-based power humps.	1) Lower power generation when compared to other mechanical-system-based power humps.
		2) Gears are not used, hence, lower losses.	2) The negative pressure inside the cylinder results in a longer time period for upward movement of the dome.
5)	Bicycle pedal	1) Generated electrical energy is a factor of both the weight and velocity of vehicle passed.	1) Chain is required, so regular inspection is necessary.
		2) Lower spring requirements.	2) More mechanical parts result in higher mechanical losses.
6)	Piezoelectric method	1) No mechanical parts are necessary, hence, lower losses.	1) Costlier compared to many mechanical based systems.
		2) Since the semiconductor material is kept outside the road, digging of the road is not necessary.	2) Life of semiconductor devices is susceptible to many environmental factors.

The maximum electric energy that can be extracted from the system depends on the number of piezoelectric materials installed, weight of the vehicle, and impact with which it strikes the piezoelectric material. The major advantage with this type of system is that it is free from moving mechanical parts. As a result, maintenance is much less costly compared to its mechanical counterparts. Also, unlike many of the mechanical-system-based power humps, digging up the road is not necessary. Installing greater numbers of piezoelectric materials per unit area can easily deliver a few kilowatts of average electrical power when a vehicle weighing a few kilograms passes over it. However, additional measures to be adopted to make the system immune to heavy vehicles so that they can be installed on national highways.

Applications of power humps

Power humps are being implemented in many countries as a significant source of on-road power generation. According to *Scientific American*, a power hump (designed by New Energy Technologies, a Maryland-based company) has been installed at a Burger King fast-food restaurant on U.S. Highway 22 in Hillside, New Jersey. The installed power hump consists of small plates that can move up and down when vehicles pass over it. This up and down movement is utilized for electricity generation, as illustrated in the preceding section. It was claimed after testing that the power hump can generate up to 2,000 W of instantaneous power when a vehicle passes over it at a speed of 5 mi/h.

For overcoming the energy crisis in South Africa, power humps are being designed for installation in national highways. The electricity generated will be utilized for lighting small villages near the highways.

Power humps also have applications in toll booths on highways, where the power generated can be used for meeting the electricity demands of the toll booths. This assists in achieving self-sustaining toll plazas, which helps ease energy demands. Another application of power humps is in multiplex/shopping mall parking lots. Currently, multiplexes/shopping malls provide parking facilities to their customers, often in underground paking garages. Power humps installed in these areas can provide electricity for lighting and air-conditioning systems. Traffic signal points are another major area where power humps are useful. The electricity required for traffic lights is either generated from solar panels installed nearby or taken from the utility grid. Installing power humps at traffic signal points allows electricity to be generated from the vehicles traveling the roads for which the traffic lights service.

Conclusion

Distributed renewable-energy-based electricity generation methodologies are emerging in recent years owing to sustainability and environmental concerns regarding conventional fossil-fuel- and nuclear-fuel-based electricity generation methods. The power hump approach for electricity generation is pollution free, small in size, and easy to install. Electrical energy generated from power humps does not depend on climatic conditions as in hydroelectric power generation. As a result, power humps are receiving attention from engineers across the globe as a prominent distributed-energy source.

We have illustrated emerging methodologies for electricity generation using power humps, portraying their principles of operation and implementation details. The major advantages and disadvantages of each methodology illustrated in this article are enumerated in Table 1.

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RF wireless power transfer: Regreening future networks

Ha-Vu Tran and Georges Kaddoum

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Over the past few years, green radio communication has drawn much attention from the research community, and it has a strong impact on various aspects, such as telecom businesses, wireless technologies, and natural environments. Specifically, the cost of electricity and CO_2 emissions have been increasing due to wireless network operation. For instance, the number of base stations (BSs) is more than 4 million, and each BS consumes an average of 25 MWh/year (an estimated approximate of 80% of the total network's power consumption). Bearing in mind the environmental perspective, generating sufficient power to supply the networks causes a significant CO_2 footprint. Particularly, the overall footprint of information and communication technology (ICT) services (e.g., computer, cell phone, and satellite networks) is predicted to triple by 2020.

Recently, in moving toward a future green world, energy-harvesting (EH) techniques have shown the potential

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Although the overall implementation cost of EH solutions is higher than that of conventional ones, this cost might be more palatable after several years of operation.

to deal with the problem of energy inefficiency. There are two main advantages to this approach. First, the EH techniques harness green energy from natural sources, (e.g., solar and wind). As a result, it contributes to reducing the overall footprint and helps protect surrounding environments. Currently, the popularity of using conventional energy sources, e.g., diesel, still dominates the use of green sources. However, although the overall implementation cost of EH solutions is higher than that of conventional ones, this cost might be more palatable after several years of operation.

Another main challenge with future networks is prolonging the lifetime of smart user devices. Given this concern, EH networks have a tremendous advantage in various applications. For instance, EH is an efficient solution for reducing battery replacement costs in wireless sensor networks. Also, it can recharge the devices working in areas where the traditional power supply is infeasible (e.g., robotic devices working in toxic environments).

Nevertheless, the amount of harvested energy from natural resources, such as solar and wind, may vary randomly over time and depend on locations and weather conditions. So, harvesting energy from these sources is not controllable and sustainable. For instance, there exists insufficient sunlight at night to generate energy, and it is difficult for indoor devices to harvest solar energy. In this context, radio-frequency (RF) wireless power transfer (WPT) might be a promising approach to overcome such a drawback. In this article, we provide a comprehensive review to address the topic of regreening the future world.

Energy harvesting and green RF-WPT

In this section, we provide an overview of EH models and a discuss green RF-WPT

EH models

EH methodology might be described as harnessing energy from surrounding environments or thermal and mechanical sources and converting the latter into electrical energy. The generated electrical current can be used to supply devices by RF-WPT. Generally speaking, EH models can be classified into two architectures: harvest-use and harvest-store-use. In harvest-use, energy is harvested and is used instantly. With harvest-store-use, energy is harvested as much as possible and then stored for future use.

In the harvest-use architecture, the EH systems directly supply devices. To guarantee the operation of the devices, the power output of the EH systems should be higher than the threshold of minimum working requirements, otherwise, the devices would be disabled because there is not enough power supplied. As a consequence, unanticipated fluctuation in harvesting capacity close to the threshold causes the working devices to vacillate in ON and OFF states.

The harvest-store-use model includes a component that stores harvested energy and also powers the connected devices. Thanks to the storage, the energy can be harvested until it is sufficient for supplying the devices. Moreover, such energy might be stored for later use when there is a lack of produced energy or if the devices need to increase their performance. The storage component might include primary and secondary storage. In this context, the secondary storage can be viewed as a backup. In particular, the harvest-store-use system can make nonstable but foreseeable energy sources, such as solar and wind, more favorable.

Green RF-WPT

Over the last decade, solar, wind, mechanical, and thermal energy have been the most efficient resources in generating green energy that can be used in wireless networks. However, the main drawback of such sources is a lack of stability. In the quest for an alternative solution, the research community has explored that radio signals belonging to a frequency range from 300 GHz to 3 kHz can be used to carry energy over the air. On this basis, a transmitter can proactively recharge wireless devices by sending energy-bearing RF signals whenever it is necessary. This is the principle of the RF-WPT technique.

It is well known that EH is a green technique since it helps to reduce our carbon footprint. However, in a shared vision, the RF-WPT technique seems to be harmful to surrounding environments because it requires electricity to generate RF signals and causes electromagnetic pollution to the human body as well as interference to data transmission. By rethinking the role of the RF-WTP technique, we suggest that RF-WTP can be seen as green if

1) the RF signal carrying energy is generated using power harvested from green resources (for example, BSs are connected with outdoor energy harvesters to harvest-and-store green energy and then use such energy to wirelessly recharge indoor devices using RF signals)
2) a tight restriction is applied for increasing the transmit power [i.e., following the equivalent isotropically radiated power (EIRP) requirement approved by the U.S. Federal Communications Commission].

In our work, the RF-WTP satisfying such two conditions is the so-called green RF-WTP. The characteristics of the green RF-WPT (Fig. 1) technique are as follows.

- The green RF-WPT technique plays a role as a bridge between green energy sources and energy-hunger devices.
- The energy harvested at a receiver is foreseeable.
- The amount of harvested energy belongs to transmit power, propagation loss, and wavelength.

It is expected that the green RF resource will be one of the most interesting candidates for future applications.

A vision of future green and EH networks

A predicted model of future green networks with EH

Future networks (e.g., fifth generation) are expected to support multimedia applications to achieve 1,000-fold-higher throughput, 1,000-fold-higher mobile data per unit area, and ten-fold-longer lifetime of devices over the fourth-generation networks. To adapt this progress, the design of new cellular networks tends to be a new form, embracing a large-scale deployment of small cells. Generally, the small cells can be classified into distinct types: femtocell, microcell, and picocell. The multitier HetNet attains a promising gain in terms of spectral and energy efficiencies due to low power consumption and good ubiquitous connectivities.

On the other hand, the development of wireless networks has exceeded the limits of power consumption, especially in cellular networks. Moreover, the energy cost and CO_2 emissions have been promptly growing due to network operation. This has inspired researchers with a challenging topic: future green wireless networks. As a promising solution, EH techniques exploit natural sources and then contribute to reducing the overall footprint and extending the network lifetime. Nevertheless, natural resources may not always be available to all devices. For instance, it is difficult for indoor devices to harvest solar energy. This yields another trend—BSs connected with outdoor harvesters that can harvest and store green energy when natural resources are available. Then, BSs use such energy to wirelessly charge user devices using RF signals.

Another approach to future green networks is the concept of the green Internet of Things (IoT). The IoT is an emerging trend where billions of identified low-power devices (e.g., sensor nodes) are connected to each other without the need for human interaction. It can provide solutions to cut CO_2 emissions, reduce electromagnetic pollution, and improve energy efficiency. For instance, with the tracking of motion sensors, the lights in rooms would be turned off when no one is inside. Also, green IoT technology can monitor energy use in high-tech buildings to reduce waste.

The green IoT is expected to enhance all technical, economical, and environmental benefits. In particular, IoT network architectures mainly rely on the platforms of wireless sensor networks (WSNs) and cooperative networks to connect devices together. In this area, battery recharging for a large number of IoT devices is challenging. Therefore, enabling the green IoT concept for future networks requires advanced solutions of prolonging a device's lifetime, resource management, and energy-efficient communication protocols.

Taking all of these challenges into account, in the following sections, we further discuss several potential concepts to move toward green future networks (Fig. 2). Specifically, challenges in implementing each concept are identified.

Enabling the green IoT concept for future networks requires advanced solutions of prolonging a device's lifetime, resource management, and energy-efficient communication protocols.

Green radio communications

Full-duplex networks

As mentioned previously, indoor devices that might not harvest green energy directly can be wirelessly powered by RF signals sent from BSs. This has inspired a combination of the full-duplex and simultaneous wireless information and power transfer (SWIPT) techniques. At the same time, the devices can receive energy in the downlink transmission while conveying information in the uplink connections to boost spectral efficiency.

We will discuss two potential research issues of full-duplex SWIPT systems. First, the antennas at the full-duplex node are conventionally divided into transmit and receive sets. To improve the performance of SWIPT systems, an advanced form of the full-duplex technique that each antenna can simultaneously send information/energy and receive energy/information in the same frequency band is highly desirable. This approach mainly depends on new hardware designs and the innovation of self-interference cancellation techniques. Second, full-duplex the SWIPT small-cell BS can

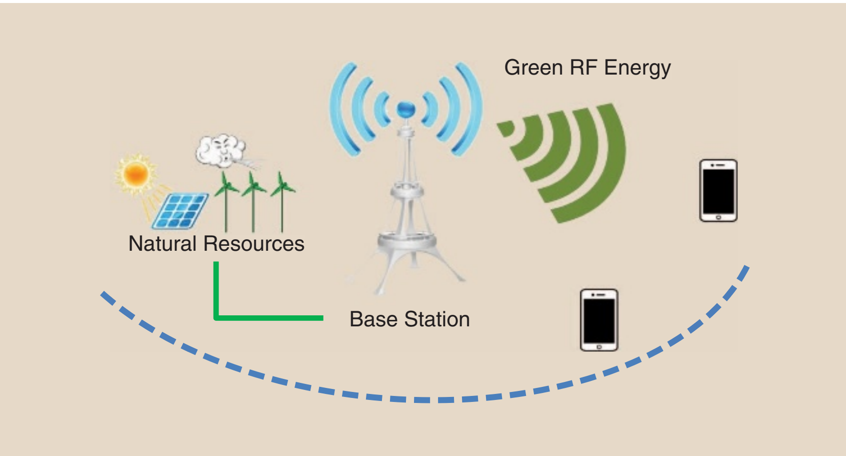

FIG1 A green RF-WPT.

Considering the existing challenges, the enhancement for both spectral and energy efficiencies in cooperative relay networks with the green RF-WTP is remarkable.

provide a promising approach regarding wireless backhauls in HetNets. In downlinks, the small-cell BS can receive information from the macrocell and transmit information/energy to users simultaneously. In uplinks, the small-cell BS can receive information/energy and send information to the macrocell at the same time. On this basis, the small-cell BSs do not require a separate frequency band of backhaul connections. As a result, resources and implementing costs are reduced.

Miliimeter-wave networks

Benefitting from millimeter-wave (mm-wave) transmission, the overall electromagnetic field (EMF) exposure and power consumption per bit transmitted of networks are reduced due to a higher free-space attenuation at the mm-wave frequency, high-directive antennas, and short distance links. Therefore, mm-wave communication is considered a primary candidate for future green cellular networks. This approach is expected to achieve multigigabit data rates due to large spectrum resources at an ultrahigh frequency band. Specifically, EH devices can extract energy from incident RF signals. Moreover, in mm-wave systems, many BSs are densely deployed to ensure proper coverage for ultrahigh frequency networks. This is attractive for EH devices to potentially harvest sufficient energy.

In ultrahigh-frequency bands, the mm-wave signals mainly suffer from the propagation loss, such as poor penetration and diffraction. To make mm-wave networks more favorable for SWIPT, beamforming techniques are a promising solution to increase the network coverage and system performance. Moreover, in mm-wave networks, although the small wavelength signals allow large antenna arrays to offer high beamforming gains, they require the alignment between transmit and receive beams to reach the highest possible performance. With these concerns, there is a nontrivial problem of the beamwidth design. In practice, the length of beam-searching overhead is directly proportional to the number of beamformer candidates. The narrower the beamwidth, the greater the number of beamformer candidates, and the longer the overhead. This leads the time of data transmission to be decreased. In constrast, a wider beamwidth means that it is easier for transmit and receive beams to be

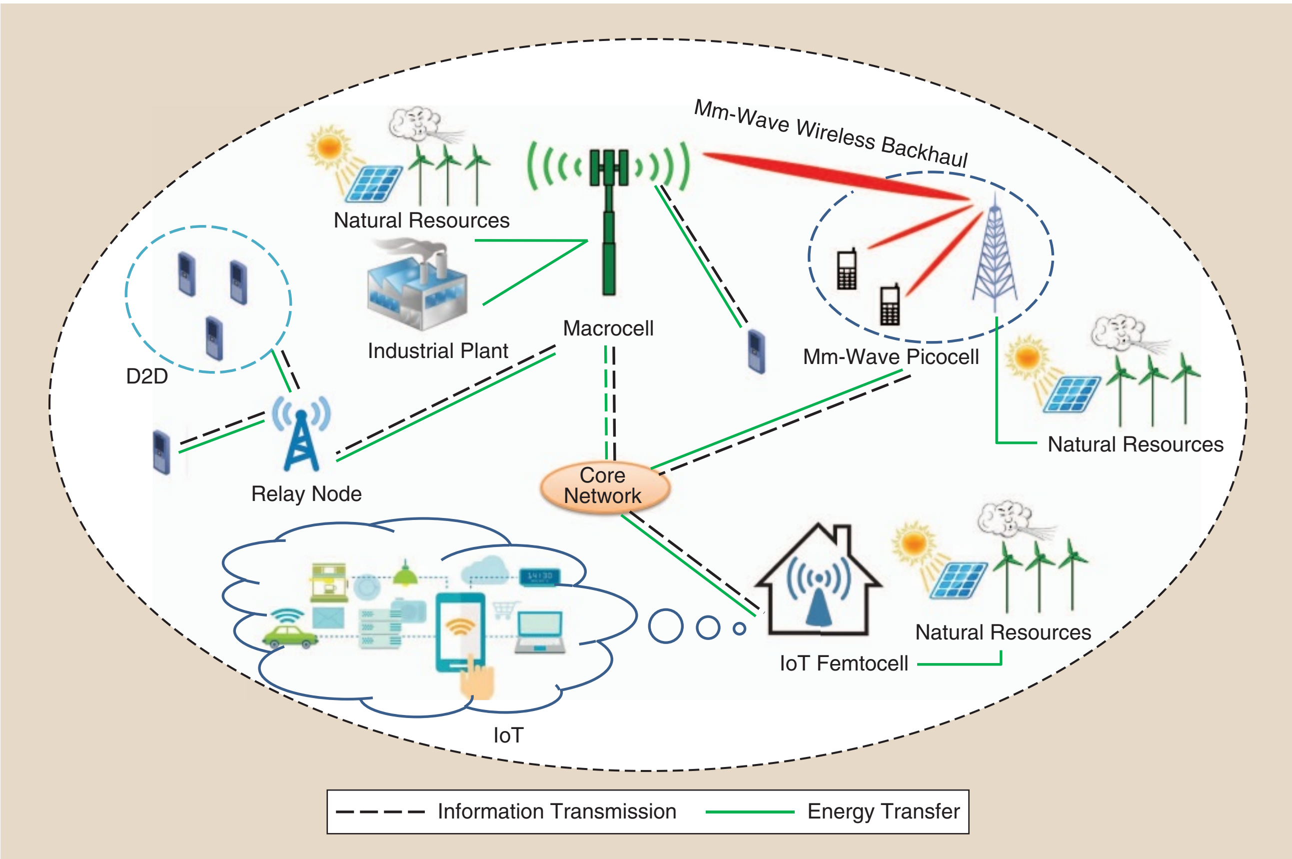

FIG2 A future green network.

aligned, and the beam-searching process is sped up, however, the beamforming gain is reduced. Therefore, future works should consider the impact of beamwidth in various contexts to maximize the SWIPT system performance.

To facilitate the regreening process while adopting intensive system performance required in future networks, the combinations of techniques, such as SWIPT, mm-wave, and full-duplex, can produce outstanding outcomes.

WSNs

Over the last few years, the trend toward WSNs is one of the most attractive options due to flexible installation and convenient maintenance. Accordingly, many standards such as WirelessHART, WIA-PA, and ISA100.11a have been proposed. Particularly, the IoT technology is mainly implemented on the WSN platform. With an integration of the IoT with sensors, sensor devices can be interconnected with the global Internet to provide solutions for future networks, such as reducing wasted energy in high-tech buidings.

Specifically, replacing or charging the batteries in IoT WSNs may take time and additional costs due to a large number of sensors, and this process becomes dangerous in hazardous environments. As a result, EH from natural resources and RF signals for WSNs have been considered a promising solution to prolong the sensor's lifetime.

The main distinction from conventional WSNs is that EH-WSNs require new criteria regarding information transfer and EH requirements. In fact, the network can fail to adapt the EH requirement while ensuring other system performances, such as throughput, delay, or packet loss. As a result, leveraging data transmission and EH is one of the critical concerns in designing EH-WSNs. Therefore, efficient resource allocation schemes should take this problem into account to achieve high energy efficiency for EH-WSNs.

Cooperative relay networks

Recently, cooperative relay networks have been evaluated as one of the main core networks for the IoT technology where IoT nodes can communicate with each other and forward information and energy to remote nodes. Up until now, many mature research works of cooperative communication have clearly shown that the relay can be implemented not only to extend the coverage range but also to improve the performance of wireless communications. Furthermore, the concept of EH/WPT relay networks has been proposed and studied to enhance the lifetime of devices and overall performance of wireless networks. In cooperative EH/WPT relay networks, improving performance gain on the physical layer is one of the main research directions.

Considering the existing challenges, the enhancement for both spectral and energy efficiencies in cooperative relay networks with the green RF-WTP is remarkable. In this area, full-duplex or two-way relaying methods may be a promising solution. It is suggested that developed resource allocation schemes should consider the influence of incomplete channel state information (CSI) (e.g., the relay nodes have a partial user's CSI) and the energy status at the relay nodes and users (e.g., the available energy, current power consumption, predicted energy harvested from natural resources, or RF signals, among others) on system performance.

Future research issues

In the previous section, several challenges of each concept were presented. In future networks, since wireless communication systems are expected to be a mixture of various novel system concepts to enhance both the spectral and energy efficiencies, we discuss some interesting combinations of the existing concepts.

Full-duplex communications meet mm-wave SWIPT networks

A combination of mm-wave and full-duplex SWIPT systems, as shown in Fig. 3, is interesting. Most of the recent research on full-duplex SWIPT systems mainly address the communications in conventional frequency bands. However, in mm-wave frequency bands, there are two main challenges that must be discussed. First, the practical implementation of mm-wave full-duplex SWIPT should be investigated with a bandwidth of several gigahertz. Second, in mm-wave networks, the

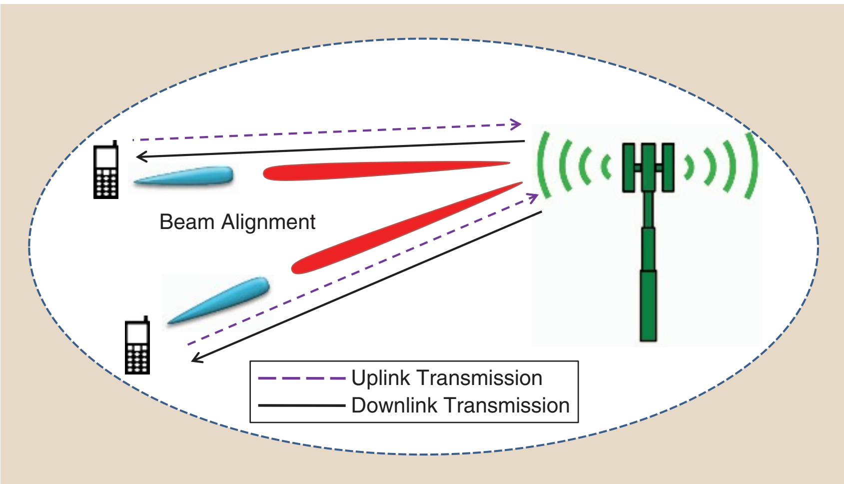

FIG3 Mm-wave SWIPT networks with full-duplex communications.

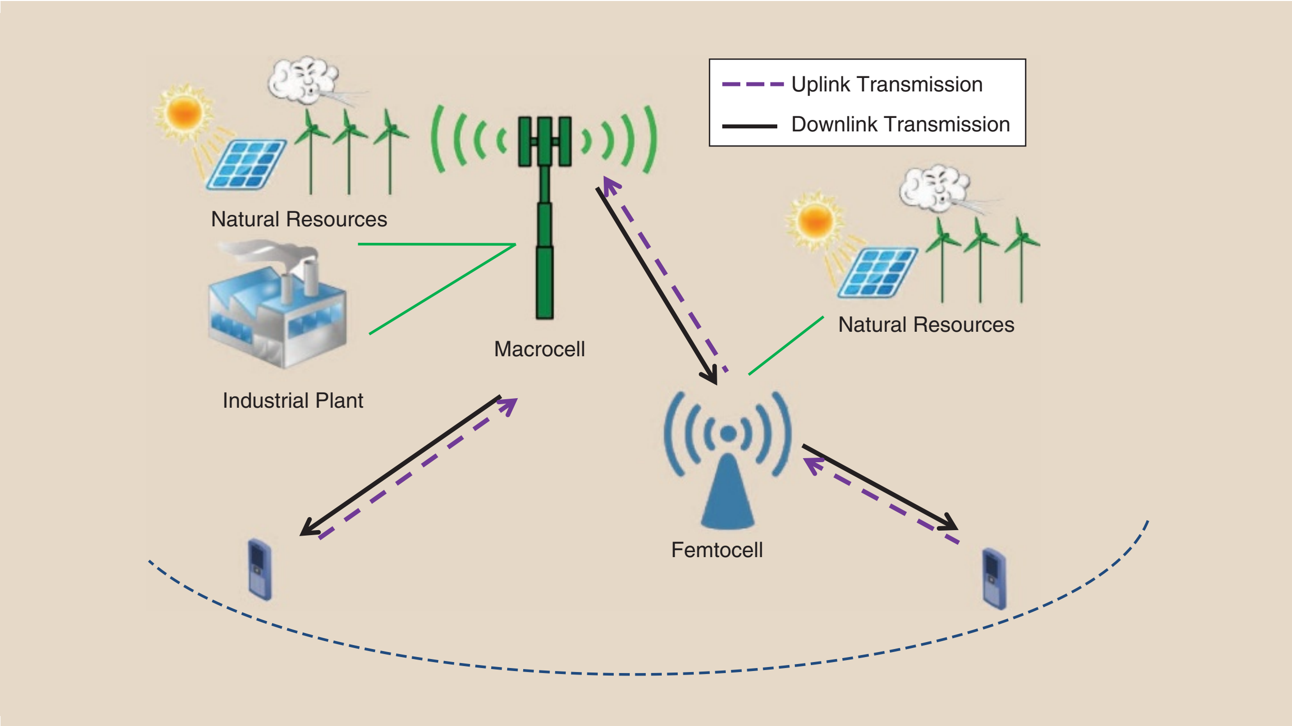

FIG4 SWIPT and EH HetNets with the full-duplex technique.

communication is inherently directional. Therefore, at both the transmission and reception sides, the directional antenna should be used. As a result, the node structure should be reconsidered according to the characteristics of mm-wave signals. To reduce the cost of antennas (i.e., parabolic antennas), one of the efficient solutions is to employ transmit and receive beams to limit self-interference. Therefore, the future objectives should address

- studying how the beamwidth affects the beam alignment, beamforming gain, and beam-searching process
- investigating the performance tradeoff between self-interference and data transmission time
- properly allocating available resources to optimize system performance.

Potential scenarios for SWIPT and EH HetNets with the full-duplex technique

Full-duplex EH-SWIPT HetNets may bring a bright (however, challenging) approach. Given this concern, in Fig. 4, a macro cell BS harvests energy from natural sources and then communicates with a small-cell BS. On the other hand, whereas the small-cell BS receives information from the macro cell, it transmits information/energy to the users at the same time. In another case, the small cell BS transmits information to the macro cell while it receives information from the user simultaneously.

Given these scenarios, the system benefits from an enhanced spectral efficiency, however, many interference sources (e.g., self, intercell and intracell) appear due to full-duplex communications. Specifically, dealing with downlink-to-uplink interference is a big challenge, since the downlink power dominates the uplink one, in general. Therefore, using

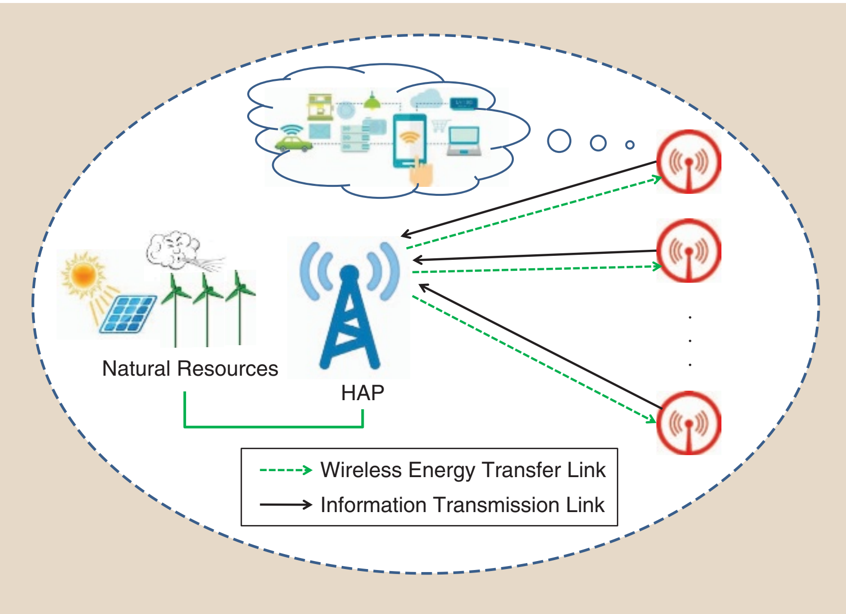

FIG5 RF-WPT IoT networks.

optimization frameworks, future works need to focus on

- designing new self-interference cancellation techniques
- managing the downlink-to-uplink interference
- allocating resources to optimize system performance in terms of information and power transfer.

The main concerns of wirelessly powering IoT networks

Due to large-scale deployments of IoT networks, replacing or recharging a device's battery is one of the main challenges. Specifically, a large number of IoT sensors are implemented in indoor locations where natural resources might not be available to harvest. In this context, the green RF-WPT is a promising candidate for prolonging the lifetime of IoT low-power devices. This implies a scenario, as illustrated in Fig. 5, where a sink node is responsible for harvesting energy from natural resources and then wirelessly transferring power to devices in a IoT wireless sensor network. In addition, the devices can communicate with each other. Given the model, some important concerns need to be addressed including

- scheduling the power transfer to energy-hungry users according to the harvested energy at the sink node
- exploiting interference from ambient environments to improve the EH performance
- maximizing information performance while satisfying EH requirements.

Conclusion

In this article, we presented a review of the promising trends toward future green networks. Based on the platform of EH techniques, several potential concepts such as HetNet, mm-wave, and IoT networks, have been discussed. In particular, we focused on a promising architecture: the green RF-WPT, which plays a crucial role as a bridge between natural energy resources and smart energy-hungry devices. Accordingly, we have shown a vision of future green networks in which smart devices can be recharged by green resources even when they cannot harvest energy directly.

Furthermore, to facilitate the regreening process while adopting intensive system performance required in future networks, the combinations of techniques, such as SWIPT, mm-wave, and full-duplex, can produce outstanding outcomes. It is expected that the green RF-WPT-based approaches can be one of the potential solutions for regreening the future ICT world.

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How is earthing done?

N.A. Sundaravaradan and M. Jaya Bharata Reddy

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Power continuity and electrical safety are essential for all industrial and commercial applications. Some of the calamitous effects created by faults in a system include loss of power, destruction of equipment, and injuries to operating personnel, each of which can be considerably reduced by proper earthing of the electrical system.

For effective protection of a system by earthing, the earth resistance value must be within a precise range. As a result, the installation of earthing system must be meticulously performed. The earth resistance depends on the earth electrode as well as the soil surrounding it. This article discusses the factors affecting the resistance of an earthing system, measurement of earth resistance, and the construction process of an earth pit.

What is earthing?

Earthing is one of the most common provisions for protection in a power system. In electrical engineering, *ground* or *earth* can refer to a common return path for electric current, a reference point in an electrical circuit or a direct physical connection to the earth. In a power system, earthing is the process of connecting a noncurrent carrying part of an electrical system or some electrical part (such as neutral point in a star-connected

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system) to earth, which is soil. In all of these cases, a connection to the earth is made through the earth electrode. An earth electrode is a conductor or group of conductors that provide electrical connection to the earth. Most electrical engineers know what earthing is but only a few know how it is done. We explain various factors that affect the earth resistance and how earthing is performed.

There are myriad uses and advantages of earthing a system. Some of them include:

- the magnitude of transient overvoltages is reduced
- locating ground fault is simplified
- improved fault protection for a system or equipment
- greater safety of operating person and reduced risk and probability of injuries or accidents
- improved lightning protection.

Why is earthing resistance value important?

Earthing serves its purpose only if its resistance is within a precise range of values, and this value is, in general, made as low as possible to provide an easier path for current flow during abnormalities. For example, consider earthing designed for protecting people who handle electrical equipment. In a properly earthed system, when a live conductor comes in contact with a metallic part due to insulation failure, the current will flow through the earth conductor and not the human body when a person accidentally touches the metallic part. If the earth resistance is high, the human body would be the lower resistance path for current flow and the purpose of earthing is lost.

Furthermore, as the earth's resistance is nonzero, a potential difference between the grounding electrode and a distant reference point is created when current is injected into the earth through the grounding electrode. This potential rise can cause hazards. In general, the maximum allowable resistance is around 5Ω for one earth electrode and 1Ω for the total earthing system, which includes all the earth electrodes connected in parallel.

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Resistance of an earthing system

The total resistance of an earthing system comprises:

- resistance of the (metal) electrode
- contact resistance between the soil and the electrode
- resistance of the soil from the electrode surface in the direction of flow of current outward from the electrode to infinite earth.

The major contributing factor to earthing resistance is the soil resistance, whereas the other two factors are small fractions of an ohm and can be neglected for all practical purposes. The following sections explain the various factors that affect the aforementioned parameters.

Factors affecting soil resistivity

Type of soil

Soil is characterized by several physical properties such as its grain size, distribution, and closeness of packing. These factors affect the manner in which moisture is held by the soil. Some of these factors may vary locally or seasonally. Soil resistivity depends not only on the ground layers of soil but also on the underlying geological formations.

Moisture content of soil

It has been observed that resistivity is only slightly affected when the moisture content is above 20%. When the moisture content is below 20%, the resistivity increases rapidly with the decrease in moisture content. Because of this, even a small change in moisture content by a few percentage points will have a significant effect on the usefulness of earth connection when the moisture content is below 20%.

However, moisture alone is not the major factor for the resistivity of soil. Moisture is required by the soil to form a conducting electrolyte using other elements available in it. Thus, if the water is pure, the resistivity of the soil will be high. High moisture content of the soil aids in increasing the solubility of existing elements in it. In some cases, chemicals are artificially introduced to improve the conductivity of the soil.

Soil temperature

The effect of soil temperature is significant only at or near freezing point. Soil resistivity increases (significantly when below 0 °C) with a decrease in temperature. As a result, it is important to install earth electrodes at depths where frost will not penetrate, that is, well below the frost line. There may be some variations in resistivity despite the rods being driven below the frost line. This is because when the upper soil is frozen, it presents an increase in soil resistivity. This acts like reducing the active length of electrode in contact with the soil.

Effect of current magnitude

Soil resistivity near a ground electrode depends on the amount of current that flows into ground. This may affect the moisture and temperature levels of soil which then affect the resistivity of the soil. Therefore, suitable electrode sites and methods of preparing the site need to be selected to obtain optimum resistivity.

Earth pit location

Dry sand, gravel chalk, limestone, granite, and very stony ground should be avoided while selecting a location for constructing an earth pit. A site should be chosen that is not naturally well drained. A waterlogged location is not essential,

The number of earth electrodes required for a particular installation is decided by the optimum value of the earth resistance required for that system.

unless the soil is sand or gravel. In general, there is no advantage in increasing the moisture content above 15–20%. Care should be taken to avoid a site that is kept moist by water flowing over it (for example, by a stream of water) as the beneficial salts may be entirely washed away from the soil.

The electrode contact resistance can be improved by performing soil treatment. Especially in those cases where a large number of rods fail to produce adequate low resistance, artificial treatment of soil is used to reduce soil resistivity. Charcoal, soft coke, sodium chloride [(NaCl) also known as common salt], sodium carbonate (Na_2CO_3), calcium chloride ($CaCl_2$), and copper sulphate ($CuSO_4$) salt are some of the most commonly used substances for this purpose. An important factor that needs to be considered while applying agents for the artificial treatment of soil is that nearly 90% of the resistance between a driven rod and earth is within a radius of about 2 m from the rod.

The efficiency of the system decreases gradually over time because of the migration and leaching of applied chemicals, thus requiring constant monitoring and replacement of the additives. Ecological considerations are essential before such treatment is commenced, and their effect on the electrode material must also be taken into account.

Electrode material

Electrode material does not affect initial earth resistance significantly. Appropriate precautions need to be taken while selecting the material so that it is resistant to corrosion in the type of soil in which it will be used. Tests in a wide variety of soils have shown that copper, whether tinned or not, is more suitable compared to ferrous materials (for example, cast iron, wrought iron, or mild steel). Galvanized mild steel is also observed to be a little inferior to copper in this regard.

While selecting and designing earth electrodes, care should be taken regarding the thermal rating of the electrode. The electrode must be able to withstand the heat produced due to current flow (current density) through it.

Dimensions of electrode

When pipes are used as electrodes, the resistance to the earth reduces drastically with length for up to 2 or 3 m (electrode length). At a further distance from the ground such as beyond 4 m, there is hardly any fall in the resistance value. If an imported fill exercise has been carried out, the conditions of the upper layers may be altered considerably. In these cases, deeper driving of the electrode into the ground may be necessary to reach layers of reasonable resistivity and also to reach stable ground, so that the value of the electrode resistance remains stable even if the top layers of the ground is affected. In general, a number of rods in parallel are preferred to a single long rod for obtaining lower resistance value.

When the diameter of the earth electrode is increased, there is an improvement in the mechanical strength of the electrode. Apart from that, no significant changes in earth resistance is observed in terms of an increase in contact surface area with the soil. Generally, an electrode with a suitable diameter and having adequate strength to withstand bending or splitting while being driven into the particular soil conditions is chosen. The larger the diameter of the electrode, the tougher it is to drive it into the earth.

The number of earth electrodes required for a particular installation is decided by the optimum value of the earth resistance required for that system. The main criterion is that the value of the earth return resistance should not be so high that it does not produce the required ground fault current for actuating the protective devices within the stipulated time.

When the electrode is a plate instead of a pipe, the approximate resistance to earth of a plate is directly proportional to the resistivity of the soil and inversely proportional to the square root of area of both sides of the plate.

The minimum size of plate electrodes is 60 cm $\times$ 60 cm. The plate electrode must be a minimum of 6.3 mm thick if it is made of galvanized iron (GI) or steel or at least 3.15 mm thick if made out of copper. The plate electrode should be buried at a depth such that its top edge should be at least 1.5 m from the surface of the ground.

Measuring earth resistance

Soil resistivity varies more with depth compared to its variation with horizontal distances. Stratification of earth layers is the main reason for a variation in resistivity with depth. The homogeneity of the soil can be identified from the resistivity measurements. If the soil is uniform, conventional methods are used to calculate earth resistivity. When the soil is nonuniform, either a gradual variation or a two-layer model is used for computing earth resistivity.

Wenner's four-electrode method

The most common method used to find earth's resistivity is Wenner's four-electrode method. According to this method, four electrodes are driven into the earth along a straight line at equal intervals. When current is passed through the two outer electrodes through the earth, a voltage difference between the two inner electrodes is developed and this is measured. As the electric field produced by current flowing through the earth is proportional to the resistivity of the soil, the voltage measured between the inner electrodes is also proportional to the resistivity of the soil. Using this, the earth's resistivity can be found. A single instrument consisting of a current source and a meter that can read the resistance directly is commonly used for testing.

Test locations

A minimum of eight different test directions are chosen from the center of the site to evaluate the earth's resistivity of the region considered for a substation or a generating station. A test can be performed in more directions for larger station sites. If the test results obtained at various locations show a significant difference, it indicates variations in soil formation.

After obtaining resistivity at several different directions, earth resistivity is determined as follows. During the course of the aforementioned tests, it is desirable to collect information about the horizontal and vertical variations in earth resistivity of the site under consideration to accurately obtain the value of resistivity to be used for design calculations. The vertical variations can be identified by repeating the tests at a given location in a chosen direction with a number of different electrode spacing, increasing from 2 to 250 m or greater, preferably in the steps 2, 5, 10, 15, 25, and 50 m or greater. The soil in the vicinity of the test location can be considered uniform if the resistivity variations are within 20–30%. Otherwise, a gradual variation in resistivity or stratification of soil into two or more layers of appropriate thickness is obtained by plotting and analyzing a curve of resistivity versus earth spacing. The horizontal variations of the earth's resistivity are obtained from measurements made in various directions from the center of the station.

The soil is considered to be uniform if the variation in earth's resistivity is within 20–30% for different electrode spacings. By increasing the spacing gradually from low values, the resistivity readings will approach a constant value regardless of the increase in the electrode spacing at some stage. The resistivity for this spacing is taken as the resistivity for that particular direction.

In a similar manner, resistivity for eight different equally spaced directions from the center of the site is obtained. These values are plotted on a graph sheet according to their directions and magnitude. A closed curve is plotted on the graph sheet by joining all the plotted points. The curve obtained is called a *polar resistivity curve*. An equivalent circle of the same area as that of the area inside the polar resistivity curve is then found. The radius of this equivalent circle is taken as the average resistivity of the site under consideration. The average resistivity obtained may be used for designing the earthing grid and other computations.

Constructing an earth pit

An earth pit is where a connection is made between earthing electrodes that have been placed inside the soil and the earthing conductor that connects the electrical installation. The following is an overview of the construction procedure of an earth pit and may vary from country to country according to the standards followed in each region. The rating of a GI plate, the size of the pit, and materials used to fill the pit will vary depending on various factors. The following procedure is generally followed in India.

- Excavate a pit to place the plate electrode.
- Use a GI plate of an appropriate size, according to the required resistance value and the standard followed in that country. This GI plate is the earth plate.
- Make a mixture of wood, coal powder, salt, and sand [all in equal proportions (the amount depends on size of pit)]. This mixture is a good conductor of electricity and also serves as an anticorrosive, ensuring a longer life of the GI plate. Coal absorbs water and keeps the soil wet. Furthermore, coal is made up of carbon, which is a good conductor, so it minimizes earth resistance. Salt helps in forming electrolyte, which increases the conductivity between the GI plate and earth. Sand, which is porous in nature, helps to circulate water and humidity around the mixture.
- Put the GI plate (earth plate) in the middle of the mixture inside the pit.
- Use a GI strip to connect the GI plate to the system earthing. It is better to use a GI pipe with a flange on the top to cover the GI strip from the earth plate to the top flange.
- The top of the pipe is covered to prevent jamming due to dust and mud.
- For the purpose of maintaining moisture content in the soil surrounding the electrode, place another GI pipe with holes in different directions along its length, such that the top of the pipe is at earth surface level. This pipe is placed adjacent to the setup. Water is poured at regular intervals using a funnel at the top to maintain the required moisture content in the soil and ensure the required low resistivity of the soil. Care should be taken by watering the earth pit in summer so that the soil is wet and the earth resistance value is maintained.

Figure 1 is a flowchart depicting the construction procedure of the earth pit. Figure 2 is a representation of a conventional earth pit that is constructed according to the aforementioned procedure.

Disadvantages of conventional grounding

Even though earthing by this method is meticulously done, taking into account various factors that affect the earthing system, there are still certain disadvantages.

1) Common salt, which is used during the construction of the earth pit, is known to be a corrosive electrolyte that can damage the pipe and conductor used for earthing. As a result, the performance of the earthing system is compromised.
2) Coal tends to become ash due to the heating effect caused by heavy electric fault current. Furthermore, the heat produced by a certain fault current will be more

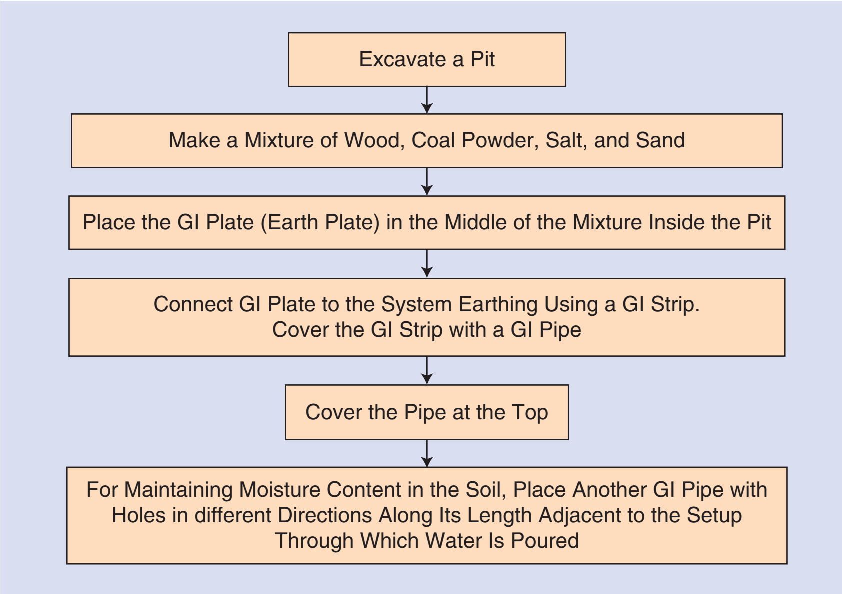

FIG1 The construction procedure of an earth pit.

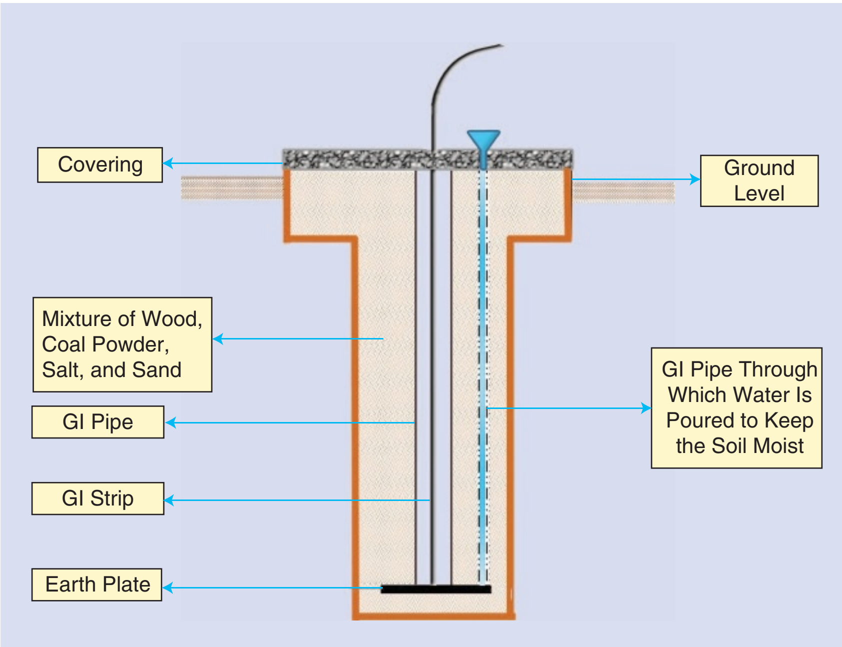

FIG2 An earth pit.

when the resistance value is high due to a faulty earthing system.

3) As the water level is decreasing in many geographical areas, one must dig deeper holes to place the earth electrode.
4) A separate watering arrangement is required for maintaining moisture content. This is done using a separate pipe, which is dug along the earthing system. Artificial watering to maintain moisture content may lead to the washing away of essential elements that produce the conductive electrolyte.

An earthing system that has a long lifetime with minimal maintenance is essential. As a result, this field presents an immense scope for research.

Conclusion

Earthing is a very important part of any electrical system because of the various uses and advantages it provides. For earthing to be effective, an appropriate low value of earth resistance must be maintained. The major factor contributing to earthing resistance is the resistivity of the soil. We explained various factors that affect soil resistivity, how to measure soil resistivity, and how earthing is performed. The aforementioned conventional method of earthing has its own disadvantages, which has also been elucidated. As earthing is of paramount importance, a vast amount of research has been performed in this area to improve it.

Read more about it

- *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, IEEE Standard 142, 2007.
- *Grounding and Bonding*, National Electrical Code Standard Section 250, 2011.
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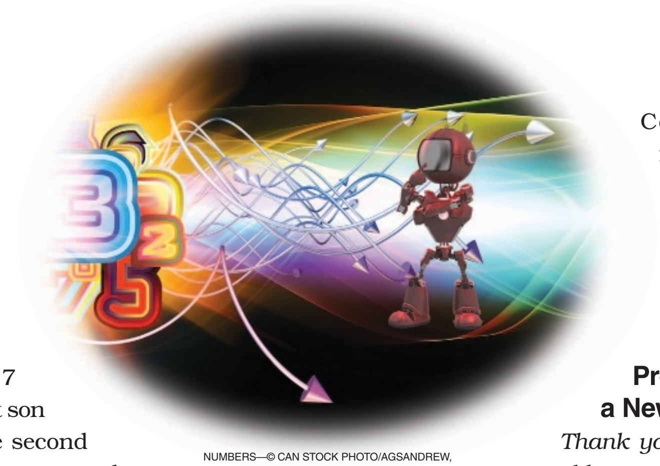

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Problem #1: No Bull

Thank you to Ai Phung for this problem.

Recent storms in Houston, Texas, left many cattle farmers selling off their oxen earlier than expected. One cattle farmer decided to retire and gave all of his remaining 17 oxen to his three sons. The first son received half of the oxen, the second son was gifted one-third of the oxen, and the last son took control of one-ninth of the oxen. Can you solve this problem so that the solution is fair to the cattle farmer's three sons?

Problem #2: The Birthday Boy

Thank you to Enrico Massoni for this problem.

Anthony was born on 1 March, but he is not able to remember the exact day of the week of his original day of birth. His mother is a mathematician, and she decided to help him to recover the exact date via a simple, but tricky, question. "Anthony, you were born on the first of March of a year that counts exactly 53 Saturdays and 53 Sundays." On what day of the week was Anthony's born?

Problem #3: Match Point

Thank you to Jonathan Alejandro Zea for this problem.

In the South American World Cup qualifiers, ten national teams participate (Brazil, Argentina, Chile, Uruguay, Colombia, etc.). How many matches are played if every team plays each other and every match is played as local and visitor?

Tip: Only focus on the qualifiers.

Problem #4: Time to Get a New Clock?

Thank you to Enrico Massoni for this problem.

Mark is an old-fashioned guy: he likes standard analog clocks. Unfortunately, this afternoon, his favorite object lost the arm that indicates the minutes, but it is still working properly. Furthermore, the hour hand is fixed in the location of the 23rd minute. Can you help Mark discover the correct time?

Problem #5: A Prime Situation

Thank you to Enrico Massoni for this problem.

Can you identify the smallest prime number for 1927555802634 + 2937482702736?

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If you have a problem for the Gamesman, submit it along with the solution to potentials@ieee.org. If we publish your problem, you'll receive a free IEEE t-shirt, so please include your size. Thanks.
Solutions are on page 6.

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