Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 8(2): 64-68
© Scholarlink Research Institute Journals, 2017 (ISSN: 2141-7016)
jeteas.scholarlinkresearch.com

# Safety Rules and Procedure for Disaster Prevention of a Sustainable Control System Design

**D.M. Ezekiel**
Department of Electrical and Electronics Engineering,
Faculty of Engineering, University of Jos, Jos, Nigeria.

---

## Abstract

A causal engineering system [i.e. a system in which before an excitation is applied at $t = T$, the response is zero for $\infty < t < T$, where $T$ is the period (Kuo, 2005)] such as a control system may suddenly become hazardous, disastrous and destructive on a scale unimaginable and colossal, due to cause and effect (causality, as defined above). Such disaster can occur if in the control system (robust, adaptive or optimal), the plant and/or controller (which both form the process) in question or the feedback element (sensor) or the filter is/are left to operate outside the region and boundary of safe operation of its design. The magnitude of such a disaster may reach an alarming and catastrophic level leading to, for example, destruction (complete failure) of the control system, factory or manufacturing unit, destroying not only human lives and other life forms sometimes, but also rendering the environment or locality where the factory or industry is situated inhabitable and unsafe for any form of life to exist there as a consequence. Example is the tragic Chernobyl nuclear energy disaster in Eastern Ukraine in 1986 or the more recent Fukushima Daiichi nuclear power plant disaster in Japan in 2011, to mention a few. They were unfortunate engineering situations and nuclear energy/power disasters of huge magnitude due to radiation and radioactivity that could have been avoided and prevented if the human operator error was avoided and eliminated by strict adherence to the safety procedures for their operation and if proper fault-tolerant equipment/elements were used to implement a robust, adaptive or optimal control. This paper therefore, shades light on control systems and also presents some safety rules that can be used to operate control systems as a proactive disaster prevention measure, in order to achieve and maintain safety and sustainability.

---

**Keywords:** causality, system, control, robust, optimal and adaptive control

## INTRODUCTION

A system is defined as a combination of components that act together to perform a certain objective (Kulakowski, Gardner & Shearer, 2006). A system that cannot be controlled is unprofitable and not useful.

*Control* is the purposeful influence on a controlled object (process) that ensures the fulfillment of the required objectives. In order to satisfy the safety and optimal operation of the technology and to meet product specifications, technical, and other constraints, tasks and problems of control must be divided into a hierarchy of subtasks and sub-problems with control of unit processes at the lowest level (Mikles and Fikar, 2007).

There are four levels of process control employing optimal, adaptive, etc. control schemes. Moving up these levels increases the importance, the economic impact, and the opportunities for process control engineers to make significant contributions. The lowest level is controller tuning, i.e., determining the values of controller tuning constants that give the best control (Michael and William Luyben, 1997). This control level may realize *continuous-time control* of some measured signals, for example to hold temperature at *constant value*. The next level (second level) is algorithms-deciding what type of controller to use (P, PI, PID, multivariable, model predictive, etc.). This level may perform static *optimization* of the process so that optimal values of some signals (flows, temperatures) are calculated in certain time instants. These will be set and remain constant till the next optimization instant. The optimization may also be performed continuously. As the unit processes are connected, their operation is *coordinated* at the third level (Mikles and Fikar, 2007). This level is the control system structure--determining what to control, what to manipulate, and how to match one controlled variable with one manipulated variable (called “pairing”). The selection of the control structure for a plant is a vitally important function. A good choice of structure makes it easy to select an appropriate algorithm and to tune. No matter what algorithm or tuning is used, it is very unlikely that a poor structure can be made to give effective control (Michael and William Luyben, 1997). The highest level is influenced by *market*, *resources*, etc. The fundamental way of control on the lowest level is *feedback control*. Information about process output is used to calculate control (manipulated) signal, i.e. process output is fed back to process input (Mikles and Fikar, 2007). The top level is process design-developing a process flow sheet and using design parameters that produce an easily controllable plant. The steady-state economically optimal plant may be much more difficult to control than an alternative plant that is perhaps only slightly more expensive to build and operate. At this level, the economic impact of a good process control engineer can be enormous, potentially resulting in the difference between a profitable process and an economic disaster. Several cases have been reported where the process was so inoperable that it had to be shut down and the equipment sold to the junk man. (Michael and William Luyben, 1997).

The primary aim of the designer using classical control design methods is to stabilize a plant, whereas secondary aims may involve obtaining a certain transient response, bandwidth, disturbance rejection, steady state error, and robustness to plant variations or uncertainties. The designer’s methods are a combination of analytical ones (e. g., Laplace transform, Routh test), graphical ones (e.g., Nyquist plots, Nichols charts), and a good deal of empirically based knowledge (e. g., a certain class of compensator works satisfactorily for a certain class of plant). For higher-order systems, multiple-input systems, or systems that do not possess the properties usually assumed in the classical control approach, the designer’s ingenuity is generally the limiting factor in achieving a satisfactory design. Two of the main aims of modern, as opposed to classical, control are to de-empiricize control system design and to present solutions to a much wider class of control problems than classical control can tackle. One of the major ways modern control sets out to achieve these aims is by providing an array of analytical design procedures that facilitate the design task.

In the early stages of a design, the designer must use his familiarity with the engineering situation, and understanding of the underlying physics, to formulate a sensible mathematical problem. Then the analytical design procedures, often implemented these days with commercial software packages e.g. MATLAB/SIMULINK, LabView, etc., yield a solution—which usually serves as a first cut in a trial and error iterative process. (Anderson and Moore, 1989)

## Significance of the Study

This paper reveals the safety rules and procedures of control systems of the 21st Century, for sustainable development. It is a technology-based approach to minimize or eliminate system failures and hazards in our industries and engineering facilities, and should accidents occur, how to reduce and manage disasters by trained personnel and professionals.

## CONTROL SYSTEM

A control system is a collection of components working together under the direction of some machine intelligence. It is a system of integrated elements whose function is to monitor and maintain a process variable at a desired value or within a desired range of values for a system parameter. In most cases, electronic circuits provide the intelligence, and electromechanical components such as sensors and motors provide the interface to the physical world. A good example is the modern automobile. Various sensors supply the on-board computer with information about the engine’s condition. The computer then calculates the precise amount of fuel to be injected into the engine and adjusts the ignition timing. The mechanical parts of the system include the engine, transmission, wheels, and so on. To design, diagnose, or repair these sophisticated systems, you must understand the electronics, the mechanics, and control system principles.

In a modern **control system**, electronic intelligence controls some physical process. Control systems are the “automatic” in such things as automatic pilot and automatic washer. Because the machine itself is making the routine decisions, the human operator is freed to do other things. In many cases, machine intelligence is better than direct human control because it can react faster or slower (keep track of long-term slow changes), respond more precisely, and maintain an accurate log of the system’s performance.(Delmar, 2000)

Control systems can be classified in several ways. A **regulator system** automatically maintains a parameter at (or near) a specified value. An example of this is a home heating system maintaining a set temperature despite changing outside conditions. The system monitors the temperature of the house using a thermostat. When the temperature of the house drops to a preset value, the furnace turns on, providing a heat source. The temperature of the house increases until a switch in the thermostat causes the furnace to turn off. A **follow-up system** causes an output to follow a set path that has been specified in advance. An example is an industrial robot moving parts from place to place. An **event control system** controls a sequential series of events. An example is a washing machine cycling through a series of programmed steps. Natural control systems have existed since the beginning of life. Consider how the human body regulates temperature. If the body needs to heat itself, food calories are converted to produce heat; on the other hand, evaporation causes cooling. Electrical control systems are a product of the twentieth century. Electromechanical relays were developed and used for remote control of motors and devices. Relays and switches were also used as simple logic gates to implement some intelligence. Using vacuum-tube technology, significant development in control systems was made during World War II. Dynamic position control systems (servomechanisms) were developed for aircraft applications, gun turrets, and torpedoes. Today, position control systems are used in machine tools, industrial processes, robots, cars, and office machines, to name a few. (Delmar, 2000).

Two terms which help define a control system are input and output. ***Control system input*** is the stimulus applied to a control system from an external source to produce a specified response from the control system. In the case of the central heating unit, the control system input is the temperature of the house as monitored by the thermostat.

***Control system output*** is the actual response obtained from a control system. In the example above, the temperature dropping to a preset value on the thermostat causes the furnace to turn on, providing heat to raise the temperature of the house.

In the case of nuclear facilities, the input and output are defined by the purpose of the control system. A knowledge of the input and output of the control system enables the components of the system to be identified. A control system may have more than one input or output.

Control systems are classified by the control action, which is the quantity responsible for activating the control system to produce the output. The two general classifications are open-loop and closed-loop control systems.

### Elements of Control System

The three functional elements needed to perform the functions of an automatic control system are:
A measurement element
An error detection element
A final control element
Control systems in the whole consist of technical devices and human factor. Control systems must satisfy

- disturbance attenuation,
- stability guarantee,
- optimal process operation.(Mikles and Fikar, 2007).

The real life practical control system design is usually developed from its prototype called model upon which the dynamic response of a system (control system, process, etc.) can be carried out to achieve a good and controllable design. The system itself places inherent restrictions on the achievable dynamic performance that no amount of controller complexity and elegance can overcome. The choices of the control system structure, the type of controller, and the tuning of the controller are all important engineering decisions. (Michael and William Luyben, 1997).

## MODELLING

If the dynamic behavior of a physical system can be represented by an equation, or a set of equations, this is referred to as the mathematical model of the system. Such models can be constructed from knowledge of the physical characteristics of the system, I.e. mass for a mechanical system or resistance for an electrical system. Alternatively, a mathematical model may be determined by experimentation, by measuring how the system output responds to known inputs. (Burns, 2001). Such a set of equations of the mathematical model completely describes the relationships among the system variables. It is used as a tool in developing designs or control algorithms. (Kulakowski, Gardner & Shearer, 2006)

An essential stage in the development of any model is the formulation of the appropriate mass and energy balance equations. To these must be added appropriate kinetic equations for rates of chemical reaction, rates of heat and mass transfer and equations representing system property changes, phase equilibrium, and applied control. The combination of these relationships provides a basis for the quantitative description of the process and comprises the basic mathematical model. The resulting model can range from a simple case of relatively few equations to models of great complexity. The greater the complexity of the model, however, the greater is then the difficulty in identifying the increased number of parameter values. One of the skills of modelling is thus to derive the simplest possible model, capable of a realistic representation of the process (Ingham et al)

Unmodelled dynamics or even a small bounded disturbance could cause most of the adaptive control algorithms to go unstable, much effort has been devoted to developing robust adaptive control algorithms to account for the system uncertainties. As a consequence, a number of adaptive control algorithms have been developed, which include simple projection, normalization, dead zone, adaptive law modification, $\sigma -$modification as well as persistent excitation. (Feng and Lozano, 1999)
The application of a combined modelling and simulation approach leads to the following advantages:

1. Modelling improves understanding.
2. Models help in experimental design.
3. Models may be used predictively for design and control.
4. Models may be used in training and education.
5. Models may be used for process optimization (Ingham et al)
6. Additionally, safety is guaranteed for modelled control systems.

## SAFETY PROCEDURES IN OPERATING CONTROL SYSTEMS

Operation of industrial controllers can produce hazards such as the generation of

- large amounts of heat,
- high voltage potentials,

- movement of objects or mechanisms that can cause harm,
- the flow of harmful chemicals,
- flames, and
- explosions or implosions.

Unsafe operation makes it more likely for accidents to occur. Accidents can cause personal injury to you, your co-workers, and other people. Accidents can also damage or destroy equipment. By operating control systems safely, you decrease the likelihood that an accident will occur. *Always operate control systems safely!* You can enhance the safety of control-system operation by taking the following steps:

1. Allow only people trained in safety-related work practices and lock-out/tag-out procedures to install, commission, or perform maintenance on control systems.
2. Always follow manufacturer recommended procedures.
3. Always follow national, state, local, and professional safety code regulations.
4. Always follow the safety guidelines instituted at the plant where the equipment will be operated.
5. Always use appropriate safety equipment. Examples of safety equipment are protective eyewear, hearing protection, safety shoes, and other protective clothing.
6. Never override safety devices such as limit switches, emergency stop switches, light curtains, or physical barriers.
7. Always keep clear from machines or processes in operation.(Ellis, 2002)

Remember that any change of system parameters (for example, tuning gains or observer parameters), components, wiring, or any other function of the control system may cause unexpected results such as system instability or uncontrolled system excitation. Remember that controllers and other control-system components are subject to failure. For example, a microprocessor in a controller may experience catastrophic failure at any time. Leads to or within feedback devices may open or short (i.e. short-circuit)at any time. Failure of a controller or any control-system component may cause unanticipated results such as system instability or uncontrolled system excitation. The use of observers within control systems poses certain risks including that the observer may become unstable or may otherwise fail to observe signals to an accuracy necessary for the control system to behave properly. Ensure that, on control system equipment that implements an observer, the observer behaves properly in all operating conditions; if any operating condition results in improper behavior of the observer, ensure that the failure does not produce a safety hazard. If you have any questions concerning the safe operation of equipment, contact the equipment manufacturer, plant safety personnel, or local governmental officials such as the Occupational Health and Safety Administration. *Always operate control systems safely!* Application-dependent objective. (Ellis, 2002)

## CONCLUSION

The major concern of control engineers is to add actuators and sensors to engineering systems called plants and then monitor these plants with controllers. *These "watchdogs" called controllers are installed in a system to maintain process variables within a given parameter.*

Controllers achieve by sending control (or error) signals to the actuators which in turn affect the behavior of the plant and the control system in general. There is therefore the need for safety in operating the complex engineering system. The safety rules enumerated look easy and straightforward yet are profound, carrying dire consequences if not strictly followed or obeyed to the letter on any control system design whether it be based on Classical control theory (frequency domain, Bode Plots, Root Locus Nyquist Plots) or on Modern Control Theory (State-Space or State variable approach based on Matrices, and vector/scalar spaces/fields); or whether it is continuous time, discrete time, delayed response or sampled data system. The price to pay for negligence, brazen disregard and neglect of the safety procedure remains the same. They are time-tested, globally accepted and in line with international best practice in control system

## REFERENCES

Anderson, B.D.O. and Moore, J.B. (1989). Optimal Control: Linear Quadratic Methods. Prentice-Hall Inc.: New Jersey, USA.

Burns, R.S. (2001). Advanced Control Engineering. Butterworth-Heinemann: Plymouth, UK

Delmar, K. (2000).Modern Control Technology: Components and Systems

Ellis, G. (2002).*Elsevier* Science: Observers in Control Systems, A Practical Guide.Academic Press: USA

Feng, G. and Lozano, R. (1999). Adaptive Control Systems. Newnes: Surrey Great Britain

Ingham, J., Dunn, I.J., Heinzle, E., Prenosil, J.E. and Snape, J.B. (2007). Chemical Engineering Dynamics: An Introduction to Modelling and Computer Simulation. WILEY-VHC VerlagGmbH & Co.: Germany

Kulakowski, B.T., Gardner, J.F. and Shearer, J.L. (2006) dynamic modeling and control of engineering systems. Cambridge University Press: London

Kuo, F.F. (2005) Network Analysis and Synthesis. John Wiley and Sons Inc.: New York, USA.

Michael L. Luyben and William L. Luyben. (1997) Essentials of Process Control. McGraw-Hill Inc.: Singapore

Mikles, J. and Fikar, M. (2007) Process Modelling, Identification, and Control. Springler-Verlag Heidelberg: Berlin

US Department of Energy (1992). DoE FUNDAMENTALS HANDBOOKINSTRUMENTATION AND CONTROL vol. 2. Washington, USA.

Xu,J-X, Panda, S.K. and Lee, T.H. (2009) *Advances in Industrial Control*: Real-time Iterative Learning Control. Design and Applications. Springler-Verlag London Ltd: London. Online source, available from: https://books.google.com.ng/books?id=1cGEwvx--GUC&pg=PA85&lpg=PA85&dq=necessary+condition+for+convergence+of+control+signals&source=bl&ots=-Y4uBAap81&sig=e_dKOcoXWL0Yr0el22GQiEfjla0&hl=en&sa=X&ved=0ahUKEwi81P2Y9NjSAhUCXiwKHZDxC6MQ6AEIODAF#v=onepage&q=necessary%20condition%20for%20convergence%20of%20control%20signals&f=false. Date accessed: 13/3/2017