Control of Powered Motion: The Unsung Driver of Human Civilization through Harnessing of Renewable Energy

Dr M.P.B. Ekanayake

What makes it possible for the human civilization to advance through the ages? The answers to this question may differ from expert to expert depending on their specialization. However, one can always identify a unique technological innovation which distinguishes the stages of human civilization. Anthropologists identify the discovery/innovation of stone tools, fire and wheel as earliest events which paved the way to human civilization. All these discoveries and innovations which shaped human civilization were fundamentally footed on the mastery of not only "harnessing" but also "controlling" the resources and energies already present in nature.

Early Beginnings

Several notable early technological advancements were inevitably related to food production. In particular, as humans domesticated animals and started cultivating crops, humans gradually developed techniques to harness the strength and power of animals and other natural resources such as water and wind. Some of those techniques are still used in their original forms to date. For example, utilizing animals to pull loads, ploughing of land, husking grains, etc.; utilizing wind flow to fan and purify grains; utilizing the flow of water as a source of mechanical energy etc. Interestingly, extracting the energy contained in the flow of water and wind, continue to be among the leading energy sources which now-a-days are called "renewable energy" sources. Though the concept of harnessing these sources were around for millennia, greater efficacy happened inevitably due to control and regulate processes.

Understanding Controls

Even from the times of using animals such as cattle, horses, donkeys or elephants to realize a task, it was necessary to "control" the motion. That is to have the animal move in a certain path or speed as desired. For example, when a horse is used to pull a coach (Figure 1), the coachman would want the horse to ride along the path at a particular speed. The path and speed may be adjusted by pulling on the reins. This "control" process is accomplished through the mediation of a human "driver" who utilizes the visual and sensory "feedback" to observe if the cart is on the right track or if there is any deviation, or an "error", from the intended motion.

Therefore, this process is a classic example of "manual control" due to the direct involvement of the human "operator" or the

Figure 01 : A horse driven coach

"supervisor" in the control task. On the other hand, it is a good example of "closed loop control" due to the direct utilization of "feedback" for the control action. However, even at the early agrarian societies, the need of "automatic control" was evident. That is, the process would "correct itself", should it deviate from the intended operation, without the involvement of a human operator. Automatic control relies on some form of electrical, mechanical, hydraulic, thermodynamic or any other form of physical (i.e. without direct human intervention) feedback process. It is essential if the process is beyond human capabilities such as requiring faster response, greater strength or prolonged activity.

Historical Development of Automatic Control

In prehistory there are various tales and folklore, most shrouded in mythology, about various "automata" which were self-operating machines. There are numerous stories and legends as well as journals and accounts of such mechanisms in many early civilizations such as Greeks, Arabs, Chinese, Egyptians, Indians etc. The first evidentially known classes of practical powered motion enabled and enhanced through automatic control (at least the ones which are properly documented in the western world) were the applications in clockwork, water-wheel and wind-mill.

Clockwork, is a catch-all phrase that utilize the energy stored in taught or compressed spring mechanisms which are winding based mechanisms used in applications such as clocks. As the storage element (*viz.* the spring) loses its energy, the clock will slow down hindering the precise keeping of time, for example. Viable solutions to this problem were presented by the Dutch physicist and inventor of the pendulum clock Christiaan Huygens (1629–1695) [Figure 2], and the English physicist Robert Hooke (1635–1703) [there are no credible portraits of Hooke as Sir Isaac Newton destroyed all pectoral depictions of him] who was also the discoverer of the law of springs and elasticity. They provided viable mechanisms based on the concept of feedback to keep the clockwork running constant despite the gradual dissipation of energy from the spring winding.

Figure 02 : Portrait of Christiaan Huygens by the Dutch painter Gaspar Netscher

(Diagrams of the relevant mechanisms are not provided here due to copyright issues.)

Their contributions are worth remembering not only for the practical implications but also for their systematic analysis of the process and dynamic systems in developing the concepts and principles of "controlling dynamic systems". Therefore, these works are considered by historians of controls engineering as representing the beginnings of control theory, which is the subject encompassing the concepts and principles of "controlling dynamic systems". Inevitably, their processes were made more rigorous and generalizable due to further rigorous development of classical mechanics and calculus led by Isaac Newton (1643–1727) and others. Ultimately the influence of these "control mechanisms" paved the way to a revolution in extracting energy a few decades later.

Controlling Wind, Water and Steam Energy – Open Loop to Closed Loop Control

Harnessing the energy contained in wind and water wheels has been a common strategy to accomplish the energy needs of industry since antiquity, as in wind mills (Figure 3) and water mills (Figure 4). There are archaeological evidence of ancient water mills and wind mills in China, Egypt, Persia and many countries of Europe. These were used in almost every facet of then industry which included grinding grains,

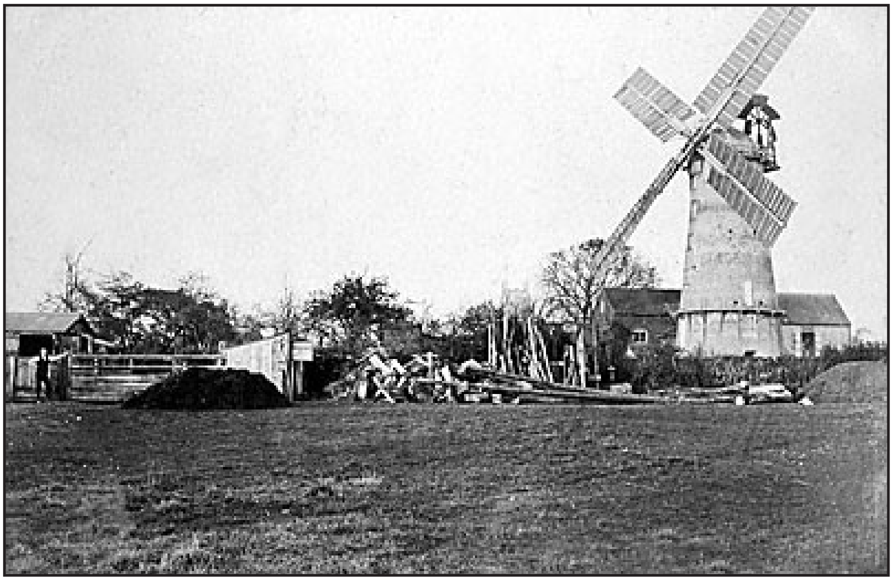

Figure 03 : View of the towermill (windmill) at Foulsham, County Norfolk, England in 1911

pumping water, irrigation and even mining operations. In 1712, Thomas Newcomen (1664–1729) invented the first versatile and commercially viable steam engine called the "atmospheric engine" adding steam energy to the energy mix. Subsequent improvements by several others culminated with the improvements made by James Watt (1736–1819) [Figure 5] who helped to drastically increase the efficiency of steam engines, making such steam engines the industry standard for energy generation. The improvements by James Watt to the steam engine were so dramatic, that some even wrongfully attribute him for the invention of the steam engine.

In either water, wind or steam models, the energy of moving substance is transferred to a useful mechanical form such as a rotary motion. In all three forms, there are fluctuations in the useful work generated due to the flow rate of the substance in motion. These common variations were somewhat mitigated using "inertial mechanisms" such as heavy rotating wheels called fly wheels or heavy rotating beams called cataracts, whose operation principle is footed on Newton's laws of motion which stipulates that a large mass will be less susceptible to sudden change of motion. These types of rudimentary controls do not rely on explicit feedback control and therefore, were simple open loop control. Their overall performance and the range of operation facilities were still limited.

Throughout the 1700s and early 1800s, water and wind continued to provide the main source of energy for many industries, especially to power mills which crushed grains which made flour out of which bread was made. Millers, especially those who used wind mills, had the nagging issue of maintaining the quality and consistency of the flour. When the wind speed increased the grinding-stones separated too much making the flour too coarse and grainy. When the wind speed was dull, the separation of grinding-stones was too little, making the flour too fine. In either extreme, the quality of the flour, and hence the quality of bread suffered. The fluctuation in the separation of grinding-stones was not something that could be adjusted by hand. So, millers were desperately in need of a mechanism to "automatically adjust" the grinding-stones so that the gap between the grinding-stones would stay constant despite the variation of the wind. In modern-day controls jargon, this would be called a "regulation problem".

Figure 04 : Water wheel and mill

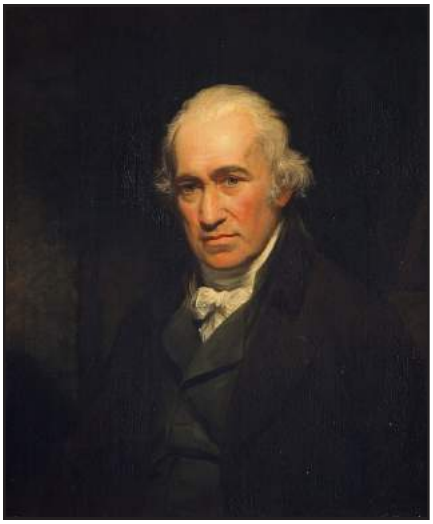

Figure 05 : Portrait of James Watt by the English painter Sir William Beechey (1806)

There were many attempts to come up with such a viable mechanism. Though somewhat similar concepts were present earlier, the first patent to such a mechanism was received in 1787 by Thomas Mead (the same person who received the patent for the gas engine). He used a cleaver trick of having two rotating masses that would rotate at a speed proportional to the wind speed. So, if the wind speed is high, those masses would rise and if the rotation speed was low, they would sag. Then, he had connected them *via* a simple lever mechanism to lift and separate the grinding-stones when the wind speed was slow and push down the grinding-stones closer when the wind speed was high so that the grinding-stone gap was consistent. This particular mechanism was anyway the first patented pre-runner to an entire class of automatic feedback control mechanisms called "governors". The name may be attributable to their role in "governing"or "controlling" the intended function (e.g. the separation of grinding-stones in wind mills) despite the variation of external energy source (e.g. wind) just like a "governor" of a city or state is expected to make sure the functions of the city or state are unperturbed by disturbances.

Mead's work inspired many more developments in the wind mill industry. In the meantime, James Watt had suffered financial losses in his innovative steam-powered mill. Later, Watt learned about the success of "governors" used in wind mills and adopted this

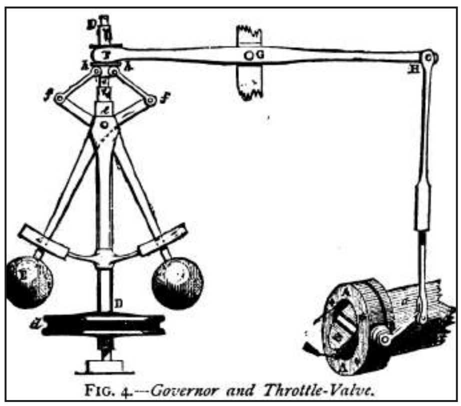

Figure 06 : Sketch of a centrifugal governor by R. Routledge in 1900

idea to steam energy driven machinery. Due to the improvements on the above type of governors these were sometimes attributed to James Watt and were known as "Watt governors", or due to their mechanism of operation as "centrifugal governors" or due to their construction using heavy balls, as "fly-ball governors" (Figure 6 and Figure 7). As these mechanical governors exert their control action based on the feedback received, they become genuine "closed loop controllers". Once governors found their way in to steam energy, they were soon developed to be much faster acting, capable of handling much larger loads and performing over a larger dynamic range. Whether it is coal, nuclear or any other fuel operated electricity generation plant, the energy source is almost always utilized to heat water and run a steam engine. Therefore, governors and other controllers played a vital role in energy generation.

When large scale hydro-electricity generation (Figure 8), and wind-electricity generation (Figure 9) picked up, as a wave of regaining popularity of renewable energy sources, those feedback control mechanisms played a crucial role in providing a reliable and consistent energy supply.

Modern Day Perspective

The control requirement of individual machines is still present in the same manner in the energy

Figure 07 : A Watt Governer on a steam engine at the Science Museum, London

Figure 08 : Victoria Dam

sector, despite utilizing new and sophisticated techniques and technologies which are in fact based on the same fundamental concepts and constructs such as centrifugal governors. However, there are new control problems, beyond what were envisioned a couple of centuries ago. These are due to the increasing renewable sources led by wind, and increasing penetration of solar photovoltaic (PV) due to continued increase in the economy of solar panels.

In the days of Mead, the fluctuation wind speed only affected the quality of flour and bread, but now it has more dire consequences in wind power generation. Fluctuation of wind induces fluctuation in the electricity generation. In solar PV generation, the electricity generation will vary due to the time of day as well as cloud motion.

Accordingly, all these sources are inter-connected and inter-mixed in a huge network called the electricity grid. There are tens of millions of consumers connected to the electricity grid. The dwindling natural energy resources and increased environmental concern has drastically raised the necessity of improving the deployment of renewable sources for electricity generation. These issues coupled with the ever-rising demand for electricity, raises major questions on the stability and control of the electricity grid.

Therefore, now we have a situation where the generation (supply) and the utilization (demand) are both varying and thereby, the control problem has not only got complicated but also diversified. The future success of human civilization, one can say, would depend on finding efficient and rapid solutions to these issues. However, rest assured, many innovative strategies are discovered and employed to tackle these problems by the best of minds all around the world, including our country.

Figure 09 : Danish wind turbines

Dr M.P.B. Ekanayake
Senior Lecturer,
Department of Electrical and Electronic Engineering,
Faculty of Engineering,
University of Peradeniya
mpb.ekanayake@ee.pdn.ac.lk