УДК 331

ДИСПЕТЧЕРИРУЕМОЕ ГИДРОЭЛЕКТРИЧЕСТВО С РАСПРЕДЕЛЁННЫМ ХРАНЕНИЕМ ВОДЫ И С ГИДРОАККУМУЛЯЦИЕЙ

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Ключевые слова: диспетчерируемое гидроэлектричество; распределённое хранение воды; гидроаккумуляция; постоянная энергия.

Аннотация: Многими было сделано большое усилие, сосредоточенное на эффективном применении и использовании энергии, и в частности, по сокращению потребления электроэнергии. То, что было пропущено, это эффективное производство электроэнергии, особенно с использованием постоянно возобновляемых водных ресурсов. Фактически, в Провинции Онтарио, в Канаде, использование воды для производства электрической энергии редко упоминается, так как ветровая и солнечная энергии являются популярными предпочтениями правительства на сегодняшний день. Огромные субсидии были выделены для этих объектов, как желание правительства представить видимые доказательства для общественности, что «что-то делается» для уменьшения загрязнения воздуха и изменения климата. Это напрасное усилие, так как ветровая и солнечная энергии не могут быть диспетчерируемыми, то есть переданными в любой момент времени, с какой-нибудь степенью энергоэффективности производства или уверенностью; вода является единственным возобновляемым источником энергии, которая может быть, как эффективно произведена, так и эффективно передана. Однако, гидроэлектростанции располагаются в отдаленных областях и являются скрытыми для общественности, и следовательно, менее привлекательными для политических заявлений. В обсуждении, приведенном ниже, рассмотрены методы эффективного использования воды для производства электрической энергии. Будет представлен обзор того, как может быть разработана интегрированная эффективная система диспетчерируемой возобновляемой энергии. Будет показано, как эффективное использование воды может сделать ветровую и солнечную энергию более эффективной. Также будет рассмотрена проблема использования избыточной энергии, которая неизбежно возникает, в основном, при развитии ветроэнергетики, для создания чистой, зеленой, химической промышленности. Это имеет значение для России!

Should obtaining an efficient quantity of hydro-electric energy be a concern when conventional hydraulic turbines presently operate at up to 96% efficiency? While the equipment at each developed site is operated effectively (in hydro-electricity, efficiency of generation is very high – mostly over 95% – with few breakdowns), installed turbine capacity is limited to capturing about 66% to 70% of the average flow in a river. This ensures that most generating units are operating at or near 100% capacity all the time, including during the summer drought when the streamflow temporarily dips far below the annual average. Whenever generation is at capacity, or when the output is not needed, the excess water is spilled unharnessed. This is a regrettable loss of production efficiency in the use of finite water resources by the hydro-electric generation industry, despite the outstanding efficient energy conversion capability of the equipment.

Spilled water represents a lost opportunity which must be recognised. Overall, only a quarter to at best a third of the available energy in a watershed is captured through hydro-electric energy generation, all at the "best" sites where there is a fortunate combination of ample head and abundant flow. The myriad of lesser interstitial sites is inevitably ignored; also, absolutely none of the additional energy contained in the freshet (spring flood) is presently captured since all of this water is spilled.

The conjecture here is that power and energy output could be increased by a factor of three or four times through a proper system redesign and the deployment of new generation infrastructure assets throughout a watershed, along with proper water management in those watersheds which are presently deemed to be "fully developed". In virgin watersheds, the opportunity is greater since the location and generation capacities of all facilities can be designed correctly for dispatchable hydro-electricity right from the start. Applied in this manner and by extrapolation, the aggregate hydro-electric potential in Ontario, including existing sites (8,000 MW), is about 100,000 MW to 120,000 MW and the energy is about 490 TWh to 570 TWh[1]. At the resulting rates of energy production, the value of this energy may be some C$30-billion annually at current electricity tariffs. At present in Ontario, the peak power demand has not exceeded 27,000 MW; total installed generating capacity including reserves is just over 30,000 MW. These figures are representative for other parts of the world.

Since this paper calls for all of the water to be used productively, including during the freshet, such systems could require very large generating capacities for use during the spring to accept this huge transient volume as the snow melts: The peak lasts at most only for a day as the crest of the spring flood passes. Of course, building such infrastructure would be a wasteful use of capital since much of the generating capacity will be idle for the balance of the year until the peak of the next freshet occurs. Instead, this plan calls for the impoundment of most of the excess water from the freshet at many locations high in the watershed where hydro-electric generation is not feasible (mainly because of inadequate streamflow). In effect, by diverting water into impoundment reservoirs, the freshet can be truncated down to the point where the installed generating capacity is able to use all of the remaining water without any spillage.

The impounded water serves an important purpose since it can be released during the late summer drought to top up the waning seasonal streamflow and allow dispatchable hydro-electric generation to continue at a more or less constant pace. In this way, by utilising a three-month time-shift in the flow of the freshet, what may have been considered a worthless volume of excess water which causes floods can be converted into a use which requires no further expansion of generating facilities, while also eliminating or greatly reducing flooding. This results in a more efficient use of the energy generating assets and a superior deployment of capital.

This time-shift technique does require additional capital to be expended in the construction of gated weirs to manage the controlled impoundment and release of the water. These weirs are expected to be completely voided of water just as the autumn rains begin after the autumnal equinox. The weirs are not expected to exceed two metres in height and the retention ponds which are created will be nominal in size, depending on the immediate topology. A geographic analysis is required to provide more detail regarding the number of weirs and their locations.

The impoundment weirs can serve a second purpose: During the fall and winter months, water may be diverted into them and retained when demand for electricity is low, such as on holidays and weekends. Gradually, the weirs will accumulate water each week as they hold back water which would otherwise be spilled; they are expected to be substantially or completely filled by late winter. There will be two claims placed upon the water which accumulates: First, it will supplement the streamflow as required to maintain an adequate spinning reserve as part of the operating reserve for the grid (mainly as backup for wind energy), and second, should there be extraordinary sustained demand placed on the system, the water within the weirs can be released as required to temporarily boost the dispatchable energy output to meet this sustained demand.

Time-shifting the seasonal spring flood to the summer drought will not solve the issue of negative rates[2]. In fact, the dispatchable hydroelectric system can create its own surplus energy during the late winter as the impoundment reservoirs are depleted in late winter and early spring so that they can be voided before the next freshet. Two mechanisms can be deployed to absorb this surplus energy: (a) through reverse-pumping headponds and impoundment reservoirs and (b) by establishing a green chemical industry which can absorb surplus energy in all reasonable proportions.

Using surplus energy to reverse-pump the watershed will be most valuable during the late summer when streamflow is low and additional water in the headponds will be a significant advantage. The design and physical configuration of the dispatchable hydro-electric system naturally lends itself to reverse-pumping without any further capital expenditure other than installing the pumps. During the summer months, the surplus energy would arise mostly from wind turbines at night; a minor amount will come from adjusting the levels in the various headponds of the dispatchable hydro-electric system since some headponds will fill faster than others.

At other times of the year, surplus energy can be used primarily to make "green" chemicals. For a green chemical industry, the only inputs are air, water, and the surplus energy itself. Carbon dioxide from sequestration processes[3] may also be used. The surplus energy can come from anywhere on the grid, including from wind sources as well as from water. Surplus energy may be imported if neighbouring jurisdictions have surplus energy issues (imports under these conditions usually cost for next to nothing). The green chemical industry will create no air emissions; the carbon dioxide which it may consume will be used as a feedstock for making synthetic liquid hydrocarbon fuels. This yields a zero-sum result for greenhouse gas emissions. The big advantage is that it negates the need to dig or pump an equivalent amount of hydrocarbons out of the ground, which ultimately results in the addition of new greenhouse gases being emitted into the atmosphere. Making green chemical products will have an economic advantage over other producers of the same items: The chemical output – largely nitrogen-based fertiliser and synthetic liquid hydrocarbon fuels – can be made with lower input costs since the surplus electricity input has little or no market value to the grid. In Ontario, such surplus electric energy is deemed a liability and often has a negative value [2].

Clearly, the combined hydroelectric and chemical infrastructure will require a considerable investment in infrastructure, which makes it imperative that planning for construction must be meticulous. The planning starts with the proof that the project will deliver what is promised, which is the next stage in this research. This involves crafting a computer simulation model which can have a dual use: First, it will model the flow of water through the river network and calculate the energy which can be produced, and second, it can be modified later to be used as a predictive tool to forecast the implications of operational decisions once the infrastructure is built and commissioned. Such a model will be optimised with appropriate mathematical algorithms to ensure the most efficient use is made of both the water immediately available and also the water which is predicted to arrive within the timeframe under consideration.

The computer simulation model will require the extensive preparation of input data – geographical information, historic streamflow, and historic electricity market supply (the supply mix) and demand, exports and imports, and surplus energy sold at negative rates – everything that can influence or guide the amount of electric energy is needed, and when. From the prepared input values, test data will be assembled so that the integrity of the model may be verified under varying water conditions. The output will show (in five-minute increments) the quantity of energy produced and at what time of day, the amount of water spilled, if any, the amount of surplus energy available for the green chemical industry, and a myriad of other figures relating to the operation of each dam within the system. No output for the green chemical operations will be projected, only the amount of surplus energy that may be available for this purpose.

Below are listed several possible applications for the Russian Federation:

- the impoundment reservoirs and a network of hydro-electric dams can prevent or greatly diminish flash flooding as recently occurred in southern Russia;
- the hydro-electric accident at Sayano Shushenskaya in 2009 could have been avoided, again through the deployment of dams higher in the watershed which can control the water inflow to the main reservoir;
- the annual flood of the Lena River can be tamed by extensive use of impoundment reservoirs plus hydro-electric developments; the design of the hydro-electric dams can allow for convenient reverse-pumping of the Olekma River for water exports to China during the flood period;
- the Irtysh River can be reverse-pumped for water exports from Siberia into Kazakhstan, also during the spring flood.

Each of these examples will be briefly discussed. Please note that none of these situations have been examined in detail. The opportunity is there for any government agency that wishes to contact the author.

The recent flash flooding in the Krasnodar region of south Russia was not a unique event: It had happened before and is well-known to be a consequence of a fatal combination of geography and weather. The projection is that climate change resulting from global warming will make the weather more chaotic and severe. The flash flooding will repeat, perhaps sooner and with more deadly force than was experienced in July, 2012 as global warming becomes more prevalent.

The situation can be mitigated by holding back some of the water in impoundment reservoirs. Given the intensity of the precipitation in 2012, it is unlikely that all of the surface water could have been held back when the rain arrives over a very short period of time. Nevertheless, to the extent that a substantial amount of the water can be retained, the flooding will be diminished in both scope and force. Fatalities will be reduced, but there can be no guarantee that there will be no injuries. The July storm occurred at the most inopportune time in the middle of the night; were the rising flood waters slowed by a few hours through impoundment, it may have been daylight before the flood could have peaked and many lives might have been saved.

This accident which occurred on 17 August 2009 at Sayano Shushenskaya Generating Station was a result of many circumstances occurring over a short period of time. There was a reservoir which was overfilling, a spillway which was eroding from inferior construction, and poor decision-making by operators of the plant. The erosion of the spillway was a hazard as it would eventually result in the base of the dam being weakened. Granted, had the spillway been constructed correctly there would have been no reluctance for the operators to spill all of the excess water in a timely manner and this incident would have been avoided. Sadly, 76 people lost their lives unnecessarily.

There is no means for holding back water from reaching the reservoir above Sayano Shushenskaya Generating Station. The value of such infrastructure may now be appreciated. The construction of impoundment reservoirs higher in the watershed not only will permit better regulation of the water flow, but it will also allow increased hydro-electric energy generation by regulating the flow of water into the reservoir. It is an insurance policy which pays.

From time immemorial the Lena River has flooded every spring. Most of these floods are more of a nuisance, but occasionally – perhaps once a decade – a serious flood wreaks extensive devastation all along the river. In recent years no lives have been lost as there is ample warning of the rising water and people are able to safely evacuate. Despite this, there is no way to move the buildings which are built on the flood plain and which dutifully fill with water as the flood crest passes. In Yakutia, the cost of a modest flood exceeds a billion roubles in lost productivity; a major flood as occurred in 2001 can now cost tens of billions of roubles in the capital, Yakutsk. The impairment of a major city for several weeks each year must be a concern.

Mitigation of the seasonal flooding on the Lena River involves a complex solution. Impoundment reservoirs must be capable of holding nearly the entire freshet; this is perhaps 200 cubic kilometres of storage (this must be verified by a detailed analysis)[4]. Such extensive storage will allow the impounded water to be released during the late summer when the flow in all rivers reaches a seasonal low, thereby allowing the main river to flow at a constant rate throughout all seasons of the year. This is a significant advantage for hydro-electric energy generation.

The Lena River watershed allows other features to be considered. The diversion of water into impoundment reservoirs will not capture the entire freshet, resulting in an slightly elevated level of hydro-electric energy generation during the spring period of high flow. The additional energy can be applied to reverse-pumping for water exports. Reverse-pumping the Olekma River will permit water exports to China via the Amur River system.

Also, some of the surplus energy created at this time can be exported to Omskaya Oblast which can permit water exports to Kazakhstan, as described below. Any wind energy developments within Yakutia may create additional surplus energy at night throughout the year which can be used to drive a green chemical industry.

The Presidents of both Kazakhstan and Uzbekistan have both publicly stated that they favour Siberian water being sent south for use in their countries. Through irrigation of cotton crops, both countries have diverted water from reaching the Aral Sea which is now a fraction of its former size. Water from Siberia could revive the Aral Sea and ultimately supplement the increasing irrigation demands. The recent drought in Kazakhstan (2012) emphasises the value of this concept.

This plan is more an exercise in politics than in engineering. Five political entities will be involved in Russia, including Moscow, and five countries south of Siberia will also be involved. The reverse-pumping may only take place for up to 16 weeks in the late winter and spring when there is sufficient energy from the Lena River system to drive the pumps. For the balance of the year, the infrastructure will be used for hydro-electric energy generation as the Irtysh River resumes its normal flow; to the extent that this energy is surplus to the immediate needs of the local areas, it can be sent back to Yakutia for use in the green chemical industry.

It is believed that the conjecture of this report will be supported throughout repeated operation of the simulation program under varying water conditions as supported by the historic streamflow and annual plus seasonal variations thereof. The total infrastructure cost can also be estimated; since the project relies largely on existing technology, the cost estimates will be very accurate. This will yield a degree of confidence that the system proposed will be both robust and economic. It will also provide the assurance that all the energy which can be wrung out of the water is being attained efficiently and in an environmentally acceptable manner. What is proposed in this paper is not something which might be done. It must be done if overall damage to the environment from all sources – in particular, the dangerous environmental damage from the combustion of hydrocarbon fuels and the attendant greenhouse gas emissions – is to be kept to a minimum and coal energy for electricity production is to be reduced.

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1. These figures are the result of a manual analysis performed by the author.
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DISPATCHABLE HYDRO-ELECTRICITY WITH DISTRIBUTED STORAGE AND PUMPED STORAGE

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Keywords: dispatchable hydro-electricity; distributed storage; pumped storage; sustainable energy.

Annotation: There has been a great effort by others concentrated on the efficient application and use of energy, and in particular electric energy, to reduce consumption. What has been overlooked is the efficient production of electricity, especially using sustainable water resources. In fact in the Province of Ontario, Canada, use of water for energy production is seldom mentioned since wind and solar are presently the popular preferences of the government. Huge subsidies have been paid for these installations as the desire of the government is to present visible evidence to the public that “something is being done” to diminish air pollution and climate change. This is a misguided effort since wind and solar cannot be dispatched with any degree of energy production efficiency or certainty; water is the only renewable source of energy which can be both efficiently produced and efficiently dispatched. However, hydro-electric generating stations are in remote areas, have low visibility for the public, and thus are less attractive for political announcements. The discussion below outlines the issue of the effective use of water for electric energy production. It will provide an overview of how an integrated efficient renewable dispatchable energy system can be designed. It will show how a better use of water can make wind and solar energy more effective. It will also discuss a use for the surplus energy which inevitably arises mainly from wind energy developments to power a clean, green chemical industry. There are implications for the Russian Federation!