Common area control system for six hydropower stations totalling 935 MW: The Þjórsá and Tungnaá area in Iceland

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Six of Iceland's eight largest Hydro Power Stations (HPS) are arranged in cascade on the Þjórsá-Tungnaá river system in the south-western highlands of Iceland. These plants are all owned and operated by Landsvirkjun and were designed and built at different periods of time with various technologies, some equipped with relay based control and protection systems and others with a modern SCADA system. All of the stations were initially remotely connected to a Dispatch Control Centre (DPC) in Reykjavik via Remote Terminal Unit (RTU). Grouped alarms from the stations were sent to the DPC which were then relayed to the operators on duty who would visit the stations to further assess the alarms and act accordingly. The distance from the main base to the furthest power station is 50 km.

All power plants are normally unmanned - except during routine checks, occurring approximately twice a week, cleaning once a week, and of course manned during ongoing maintenance operation.

The operational constraints due, among other things, to the distance between the plants and the response time required to ensure safe power production led to the idea of having a Common Area Control System (CACS). The purpose of the CACS project was to obtain a higher level of control and monitoring for the area by establishing a global control system to service all stations. The system was to be run on an open communication protocol so that all modern control systems of each power plant could be connected and implemented with the same operator interface at every station.

One of the main objectives of the project was to reduce the operational costs of the stations while allowing for a faster and more effective response to alarms. Significant time and transport savings could be incurred by enabling the operators to monitor the conditions of the different systems in the respective power plant from one location, allowing them to remotely check an alarm and decide if immediate assessment was needed or respective action could wait until the next working day, or alternatively be solved without driving to the station. The project was initiated in 2004, the design will be finished by the end of 2015 and implantation of the last station in 2016. In the future Landsvirkjun expect to build more power plants in the area which will be connected to the same system.

TECHNICAL INFORMATION

The Control System	
Commissioning:	2004-2016
Servers:	Redundant
Clients:	8
Local panels:	15
Number of signals:	36,511
Control network:	IEC 60870-5-104
Control system manufacture:	Andritz
The Power Plants	
Number of power plants:	6
Number of hydro power units:	18
Installed power:	935 MW
Annual generation:	6615 MWh
Number of operators on shift:	6

This paper describes the design of the common area control and monitoring system; with new systems installed in three of the stations leaving the other three stations with their original systems. The process of developing the system is described from the technical aspect together with the experience from an operational point of view and the benefits of the project for the operation of the power plants; i.e. more sophisticated monitoring, more reliable operation, better utilisation of manpower and cost savings.

1 Overview of the Hydro Power Station area

There are six Hydro Power Stations located in the south-western highlands operated by the National Power Company of Iceland, Landsvirkjun. These power stations are arranged in cascade order on the catchment area of rivers Þjórsá and Tungnaá (See fig. 1) and consecutively utilize the same water collected in four different reservoirs. Water starting from the highest reservoir down to the outlet of the last station drops a total of 500 meters to produce a total of 935 MW of power which is then distributed for use by citizens and the industry sector. This accounts for 34 percent of the total produced power in Iceland, a total of 16.495 GWh according to Landsnet, the national power distribution company.

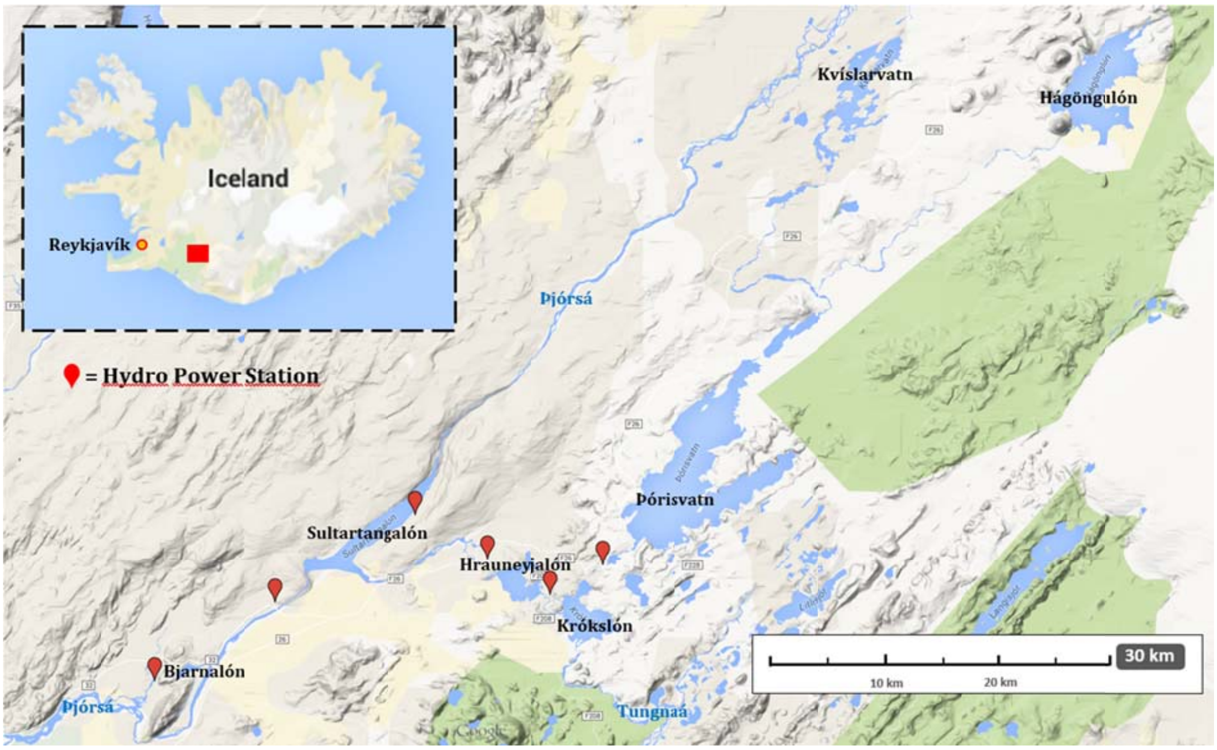

Fig. 1: Map of the highlands showing water reservoirs and sources

There are two reservoirs north of the area, Kvíslarvatn and Hágöngulón, which supply the larger reservoir Þórisvatn further south. Hágöngulón is dammed at the southern end and is monitored remotely. Þórisvatn reservoir supplies the first three stations in succession, with smaller reservoirs in between. The first of these smaller reservoirs, Krókslón, is additionally supplied by the river Tungnaá which consequently supplies the second smaller reservoir Hrauneyjalón. All water flows into the reservoir Sultartangalón which is also supplied by the Þjórsá river and utilized by the two downstream stations. Bjarnalón, located just above the Búrfells reservoir, is the smallest of all the reservoirs and serves as an intake reservoir for the Búrfell station after which the river Þjórsá continues to flow down to the lowlands.

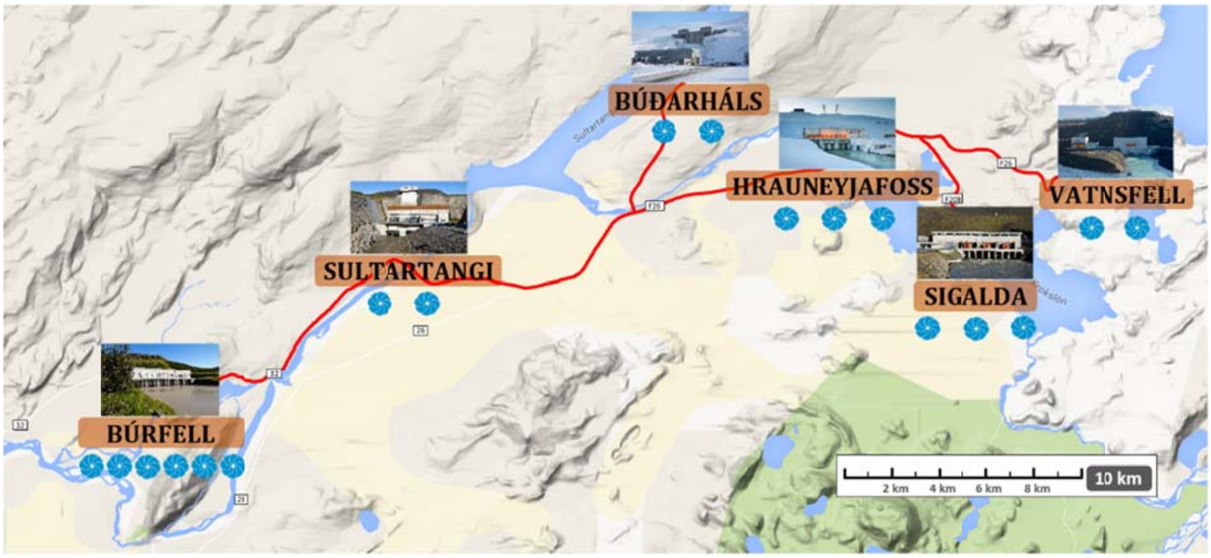

Fig. 2: Map showing the location of the six Hydro Power Stations in the Icelandic Highlands

Vatnsfell, the highest and northernmost HPS at about 600 metres above sea level, is located 50 km away from the main base at Búrfell and produces 90 MW from two Francis turbines. The station, commissioned in 2001 and supplied by the Þórisvatn reservoir, has a total head of 65 metres and unlike the other stations, it only operates during wintertime. The current control system here is of type Cegelec and will be upgraded to communicate more effectively with the new CACS.

Almost 7 km’s west of Vatnsfell is Sigalda HPS whose power capacity is rated at 150 MW produced by three Francis turbines. Completed in 1978, this station is the second oldest power station in the area with a total head of 74 metres coming from the Krókslón reservoir. The control system here was originally a BBC (Brown Broveri Corporation) control system - incidentally the first computerized control system in an Icelandic power plant - and was refurbished to an Andritz system to better handle the communication with the new CACS.

Travelling another 10 km’s west brings us to Hrauneyjafoss HPS, home to one of the CACS servers and with a rated capacity of 210 MW produced by Francis turbines. Hrauneyjafoss went online in 1981, it uses the water from the reservoir created by the Sigalda power station, Hrauneyjalón reservoir, and has a total head of 88 metres. The control system here, previously a relay based system from ASEA, was similarly refurbished to Andritz to account for the new CACS system.

Located 33 km’s north-east of Búrfell HPS is the newest station Búðarháls, coming online in March, 2014. Two Kaplan turbines produce 95 MW from the tail water of the Hrauneyjafoss station with a total head of 40 metres. Water flows from there into the Sultartangi reservoir. A Voith-Siemens control system is installed here and it communicates through a gateway to the CACS.

Downstream from Búðarháls and only 15 km’s east from Búrfell is the Sultartangi HPS which came into operation in 1999 and has a rated capacity of 120 MW produced by two Francis turbines. With a total head of 45 meters, this station uses water from the Sultartangalón reservoir which is not only fed by the water used in the higher stations but also by the Þjórsá river which means this station is more resistant to fluctuations in water flow. In Sultartangi a Schneider control system is installed with a gateway to the CACS.

The largest and oldest HPS in the area is Búrfell, commissioned in two stages in 1969 and 1972 it was the first power station of the six and serves as the main headquarters. The second server for the common area control system is located here and it is also from here that operators monitor all stations. Búrfell is the lowest and most western HPS, located only 100 metres above sea level and with a rated capacity of 270 MW produced by six Francis turbines. Búrfell has a total head of 115 metres coming from the Bjarnalón reservoir. The control system here is split between the common system and the units; the common control system is Siemens while the unit control system was a 15 year old Voith system was recently refurbished to Andritz, both of these systems communicate through gateways to the CACS.

Additional to the six power plants in the highlands, Landsvirkjun also has a separate water measurement system which collects water flow and level data from the numerous reservoirs and rivers within and above the area. In 2012, in an area of Vatnajökull national park, a small volcano erupted under the glacier which resulted in a glacial flood. This activity affected water flow and levels in the highlands and resulted in a flood in the water supply for the Hágöngulón reservoir. Since the water management system was not connected to the CACS, alarms did not communicate effectively and resulted in disruptions in the operation of the system. Future incidents are to be avoided by connecting the system and its alarms to the CACS to allow for a faster notification time.

2 Design of the Control System

Verkís, Landsvirkjun and Andritz Hydro worked collaboratively on the implementation of a new Common Area Control System (CACS) which was to serve all six Hydro Power Stations in the Icelandic highlands. Verkís worked closely with Andritz Hydro, the new control system manufacturer, both on the design and implementation of the new system as well as during the start-up and testing phase, providing continuous support to Landsvirkjun after the completion of the project. The project was initially auctioned to the team-up of Verkís and Andritz Hydro for the upgrade of the Sigalda HPS, but following this Verkís became the primary consultant engineers working directly for Landsvirkjun for the remaining parts of the project.

Before the project was started in 2004, each power station had its own independent control system and viewing the status of a neighbouring plant was not possible. Programmable Logic Controllers (PLC) and clients did not communicate between stations and this meant that operators had to physically travel to each station to assess and solve problems locally. The DPC in Reykjavík controls the power transmission system and the power output of the area depending on the demand on the power grid. This means the DPC has the authority to stop and start the generating units remotely following a predetermined plan based on calculated trends. The DPC receives grouped alarms from the area and relays them to the operators on shift.

In the initial stages of the project, a double server was installed at the Hrauneyjafoss HPS which served the control systems in Sigalda, Búrfell and Hrauneyjafoss. In 2004 Landsvirkjun first commissioned a refurbishment of the alarm system in Sigalda and later in 2006, a refurbishing of the Hrauneyjafoss HPS control system. The year 2007 saw the instalment of the Common Area Control System which was the bulk of the project. Immediately following this was a refurbishment of the operating system in Búrfell and this was consequently connected to the new CACS. In 2012 the control systems in both Búðarháls and Sultartangi were upgraded and modified accordingly to allow for connection to the main server in Hrauneyjafoss and this was completed in 2014 and 2015 consecutively. To allow for safer and more reliable operation an extra server was added in Búrfell as back-up to the one in Hrauneyjafoss. Additional to the water level and flow signals already present in the station systems, 20 more alarms and signals were added to the CACS from the separate water management system to better monitor and control fluctuations in water flow and level due to unavoidable natural occurrences such as volcanos. More signals and even more advanced monitoring is planned for this area in the future. The last phase is the refurbishing of the Vatnsfell system which is already underway and will be completed next year.

With this new setup (See fig 3), the control system has two servers, located in Búrfell and Hrauneyjafoss. These servers are redundant to each other, meaning that both are running but only one is active at any given time. Each station has its own independent control and monitoring system which is connected to the common network. There is a separate PLC unit for each generating unit and then extra PLC units for common systems such as station auxiliaries, river gates and switchgears and each of these PLC's transmits data to the two common area servers. The clients at each station, which are all connected to the same network, collect display data directly from the common area servers. Specifically, there is now just one global operator interface which means that each client displays the same operator interface containing data and alarms from all stations and even allows for remote control. The PLC's and clients are all connected in a net configuration which is completely independent of the DPC network which adds an extra layer of safety to the communication system as a whole. Having two segregated communication systems provides backup in the unlikely event that one fails and means that each system cannot disturb the other. The communication system is made up of fibre optic cables which are connected in a ring. The system uses mostly dark fibre, it has its own switches and routers and the connections are secured by firewalls.

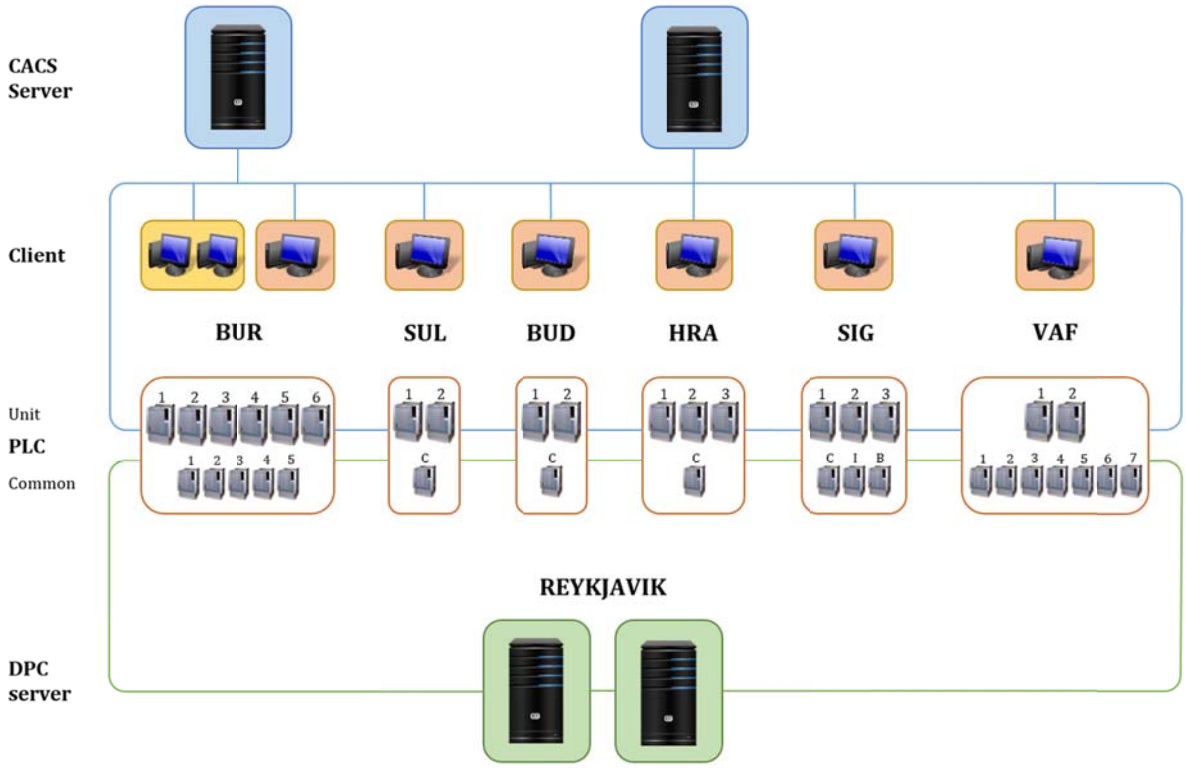

Fig. 3: The network structure of the new Common Area Control System using protocol IEC 60870-5-104

An important effort made in the design of the operator interface was to involve the operators with the design of the layout of the display to be able to tailor it specifically to their needs and consequently allow for easy control and monitoring from the operator point of view. Having a synchronized layout of screens, symbols and object use for all the six stations also provides the benefit of a single global system upgrade and operator training.

Three of the stations Sigalda, Hrauneyjafoss and Búrfell have new Andritz control systems, replacing older systems which would not have supported the new communication design. The systems in the other three stations Búðarháls, Sultartangi and Vatnsfell were not changed. In Búðarháls the control system was originally designed to be able to be connected to the CACS and in Sultartangi the upgradable system is able to handle the new communication system while upgrades are planned for the Vatnsfell HPS which will be connected via a gateway to the new CACS.

For the CACS system, communication is handled through the communication protocol IEC 60870-5-104 into the main server and for the Landsvirkjun DPC system communication is sent using the IEC 60870-5-101 or 104 protocols. Other communication methods are used internally and they include Modbus, Profibus, IEC 60870-5-103 and ODBC to name a few. Communication is globally time stamped which allows for synchronization between all clients and easier troubleshooting.

Protection relays are connected via a connection bus, the newest relays of type IEC 61850 and the older of type IEC 60870-5-103 while some even have an ABB Spa-bus connection. The separate Landsvirkjun water measuring system however runs on Microsoft SQL servers. Data from this system are connected by the CACS system for visualization on the operator displays. Long term data collected from the operation of the system are stored in an Oracle database in Reykjavik and this system logs mean values over certain time periods.

Some extra features were added alongside the CACS which serve to improve the monitoring and troubleshooting capabilities of the operators. One of these features is the installation of a GSM alarm system connected to the CACS which sends a text message to the operators on shift in the event of an alarm. Additionally, Landsvirkjun has developed a video surveillance system (See fig 4) to allow operators to see stations from the Búrfell base. This system boasts remote zooming capabilities which is especially useful in troubleshooting applications, an operator can check for example whether equipment is leaking or smoking.

3 Operation

The stations are constantly monitored by Landsvirkjun's shift operators whose base is located at Búrfell Hydro Power Station. The central monitoring base is now equipped with 6 operator monitors as well as a video wall (see fig.4). The shift rotation consists of four shifts, each with six operators. Operators work normal 8 hour days and before the CACS was implemented, all operators were then on-call the rest of the day. A full rotation consists of one week in operation, one week vacation and then two weeks of maintenance. Operators are required to monitor, and at times control, all stations and react to alarms in the system by assessing their priority and solving them accordingly. Grouped alarms from stations are sent to the DPC in Reykjavík that notifies the operators. The DPC is responsible for controlling as the stations are normally unmanned except for routine operational checks. At each station, regular maintenance checks are performed twice a week, cleaning once a week and larger maintenance tasks are performed according to the Landsvirkjun preventative maintenance schedule which plans larger tasks such as replacement of machine parts and reacts to machine failures registered by the system.

Fig. 4: The control base at Búrfell with monitors and video wall

Before the new control system was implemented, there was also a second operator base in Hrauneyjafoss HPS which saw to the control of Vatnsfell, Sigalda and Hrauneyjafoss and required four operators. This station housed the four operators and consequently employed service personnel such as a cook, cleaners and service officers. When an alarm event happened, the DPC would notify the operators and inform them of its origin. However the DPC only receives grouped alarms, meaning that alarm specifics are not given, so the operator then had to assess the importance of the alarm and act accordingly. Remotely assessing the alarm was often not a viable solution because firstly, the operator did not receive alarm specifics, secondly, the operator could not see the current details of the system from which the alarm originated, so could not make an informed decision on the urgency of the alarm. This meant that in most cases two operators would have to drive immediately to the offending power station to assess and fix the problem locally, outlaying time and money to get there. For example; an alarm originating in Vatnsfell HPS results in a minimum of 3 hours of operator transport time, more if the weather and road conditions are not ideal. During mid-winter months weather conditions can become so hostile that the roads are closed for lengthy periods of time. Not only does this pose higher transport costs and unnecessary danger to the operators but if the alarm was serious enough it could also endanger the production of power.

Fig. 5: a) Búrfell Station in winter ***b) Road closure during winter***

4 Benefits

There are myriad benefits to this enhanced control system: the CACS allows for advanced station monitoring, safer and more reliable operation, and significant cost savings in relation to man hours and transport and time reductions, which were previously factors due to the distances between stations.

After the implementation of the new control system, 70% of all callouts can be resolved directly from the operator base at Búrfell and often just by one operator, allowing for immediately apparent and significant cost reductions. This is in stark contrast with the situation before the implementation of CACS when at least two operators would respond to the callout and physically go to the offending station to solve the problem. Now, in the event of an alarm from any one of the 6 power stations after normal work hours, only one on-call operator is immediately notified through SMS additionally to the notification from the DPC. Operators are able to respond more rapidly because the SMS notification is automated and originates from the system itself so human error is not a factor. Once notified, the operator can check the alarm in the system from the Búrfell monitor base and assess the priority of the alarm, whether more operators need to be called out and the best way to solve it. It may be a simple problem which can be solved remotely, it may be a low level alarm which does not need immediate attention, leaving the operator free to complete higher priority tasks and not necessitating further callouts. Undoubtedly many alarms do require immediate and local attention in which case the operator will fix the problem locally as before, the new system simply gives them the freedom of first making an assessment of the alarms urgency and in some cases allow them to step in remotely. The operator also gets a much better understanding of the overall status of the system, if one system has a small alarm related to a bigger problem elsewhere, this connection can immediately be established because all the local systems and their conditions are displayed in one common area system, and the cause is therefore much more readily correctly determined and removed. Additionally, operators have more information available to prepare themselves and involve the right specialists before leaving the Búrfell headquarters.

The operator station at Hrauneyjafossstöð, previously requiring 4 operators plus service personnel, has been made superfluous, resulting in a merging of the two bases, offering significant cost reductions.

Special focus has been put into allowing and encouraging the area operators to solve problems related directly to the area, as opposed to the DPC. With this in mind, changes have been made to the type of grouped alarms the

DPC receives, meaning only general alarms from the whole area system are being sent to them. This has increased the operators control and troubleshooting duties resulting in the DPC notifications being more of an alarm than anything else.

The daily local station checks have been reduced to every 2 or 3 days, depending on the importance of the station, and replaced in part by the implementation of a specially designed remote daily checklist which is performed directly through the CACS system. Additionally, starting in 2013, a pilot checklist is being tested for the Vatnsfell station which reduces the local check of the station to once a week and positive results have been observed. Extensive research was done on the elements which were able to be checked by the CACS system opposed to those which needed a local check, such as smell and sound checks. The video surveillance equipment has helped substantially in this regard.

There has been a noted reduction in transport costs and time and operators gain a better understanding of the overall system and how each system connects to the other. The CACS utilizes a systematic coding system known as KKS code and, although this system is not new, operators have become more familiar with the KKS code related to each station because they must now search in the same system for different signals and operations.

Another notable improvement is the enhanced control of the water levels which require constant monitoring. The video surveillance system has helped a lot in this regard especially in summer when water levels must be held at critical levels

Perhaps the most notable and advantageous benefit of having one global system is the savings that are incurred due to the reduction of system updates. Previously, each system had to be upgraded every 6-8 years, and with six different systems, this results in a lot of time and money, not to mention inconvenience. One common system needs only one update for the same time period and in the long run these savings are significant.

Operators have given positive feedback after the successful implementation of the new system, reporting that they now get more time to complete lower priority tasks such as small maintenance tasks, measurements and sample taking. Additionally some operators have been moved to the maintenance sector over the summer time, saving the employment of relief employees. Training is also more effective because a new operator can learn about monitoring and controlling all six stations (instead of having to learn a separate system for each), using just one operator interface global to the whole area and can do this from one spot, meaning yet again, time previously spent on unnecessary transport can be effectively used for training.

To put some numerical value to these savings, the reduced local station checks have condensed the weekly commute by 400 kilometres, amounting to 350 USD while the consequent reduction in man hours has gone down by 86 hours per week, giving a total of 3500 USD. We cannot ignore the increased man hours required for the remote checks and when this is taken into account, a total of between 15-20 % of man hours is saved and can be used for other tasks.

5 Conclusion

Although a considerably prodigious and complicated project, the combination of six different operational systems has not only eased use through standardization and common operation points but has also forced a much needed upgrade of the varying operational systems at each station. By having one operating interface, control and monitoring of all stations is simpler to use, easier to learn and possible from all six stations. Operators can easily check the status and data from each station without having to rely on the DPC, which in turn eases the workload of the DPC and moves the responsibility closer to the personnel who are working directly at the stations and understand the machines best.

Logically it would take longer and be more complicated in realization when a system is added after implementation so for future power station control systems this project has gathered invaluable experience which is sure to ease implementation for future projects. A common system also opens up feasible opportunities for a separate training centre which would serve both to train new operators but also provide a platform for testing new or upgraded software and its functions.

This project clearly confirms that a higher level of control and monitoring has been obtained through establishing a global control system across all stations. Therefore, when considering the commission of future HPS systems or additions, this project endorses that a common system not only makes operational sense but it easily instigated as the system is already familiar, its operation is verified and start-up processes run more smoothly due to familiar commands and operations.

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