Information support of equipment operations – the case of a hydropower plant

P. Butala, L. Selak, and A. Sluga
Faculty of Mechanical Engineering, University of Ljubljana, Aškerčeva 6, 1000 Ljubljana, Slovenia
peter.butala@fs.uni-lj.si

Abstract

In the contribution a new product-service system business model for production equipment is discussed. It is based on a value network, which enables lasting partnership and collaboration among a customer, OEM, suppliers and service providers, and is focused on production performance and equipment utilization by providing products and related services. It is expected that due to synergetic effects of collaboration better equipment utilization could be achieved and thus additional value generated and shared among partners. The business model integrates an information service system, which supports all stakeholders with data and information related to equipment operations. The system is illustrated in the case of a small hydropower plant. It clearly exhibits economical, technical, social and ecological benefits of integrating products and services.

Keywords

Product-service system, Industrial equipment, Remote monitoring

1 INTRODUCTION

Production equipment is an important element of a production system which is needed for performing a production process. The equipment installed in discrete manufacturing, process industry or energy production is today complex high tech machinery. Not only design, development and manufacturing but also operating and the maintenance of such equipment require high level specialized knowledge and skills, which are, especially at the beginning of exploitation, usually not gained adequately by its user. The operational performance, such as the output, costs, quality, equipment utilization, availability is far from optimal, as a consequence. The root of the problem lies in the existing relation between the customers and suppliers of production equipment which are predominantly based on a traditional buy/sell relationship. This relationship is concentrated on acquisition and delivery of equipment and as such does not offer acceptable support to end users. Besides, other stakeholders and parties which may be affected or are concerned with the operations of the equipment are not considered at all in the relationship.

The customer and supplier relationship has to be transformed into a new one, with the focus on equipment utilization by providing products and related services for the entire equipment life cycle. The idea of a product-service system has been introduced. It is defined as a marketable set of products and services capable of jointly fulfilling user's needs [1]. An industrial product-service system is an integrated product and service offering that delivers values in industrial applications [2]. The way of thinking leads to new business models including new financing concepts from buying or leasing to “pay-on-production” [3]. A paradigm shift from separated consideration of product and services is observed [4].

In the work a new product-service system business model is being researched. It is based on a lasting partnership and collaboration among a customer, an original equipment manufacturer, suppliers and service providers. The model is focused on the equipment utilization by providing products and related services. It is expected that due to the synergetic effects, better equipment utilization could be achieved and thus additional value could be generated and fairly shared among partners.

The business model incorporates an on-line information service system, which provides information services related to equipment operations. The system has to make the equipment’s behavior visible to all stakeholders in real time. On this basis, needs for services can be detected and provided adequately at the right time.

In the research, small hydropower plants (SHP) are being considered as a pilot implementation area of the information service system. The prototype solution implemented on a SHP in Slovenia illustrates the approach.

2 TOWARD A PRODUCT-SERVICE SYSTEM BUSINESS MODEL

A business model defines underlying principles of how a company creates, captures and delivers value. The business models of this kind are company internal and self-centered while companies try to minimize costs of captured values and maximize price of delivering values in order to maximize profit. But capturing and delivery of value is always a game between two players, a customer and a supplier. The customer/supplier relationship has gradually developed in a commonly accepted business model regulated by national and international directives for free trade.

The purpose of the customer/supplier business model is to enable common trading among two parties. It regulates the buy/sell interactions. The model covers two trading phases, the pre-sales phase and the sales phase. In the first one, there exists a relatively loose interaction among parties, such as requesting/biding. A conflict of interests may appear in this phase due to self-centric business models of the participating companies. The conflict can be resolved by negotiations which may or may not lead to an agreement. In case of the agreement confirmed by both sides by an order/order-confirmation or a contract, the sales phase starts. The agreement is fulfilled by delivery of goods or services, invoicing and payment. During the sales phase, the common liabilities of the parties are well regulated by trade rules and laws. The liability of the customer ends with the payment and the liability of a supplier ends with expiration of a guarantee. Figure 1 shows the basic parties and interrelations of the classic business model.

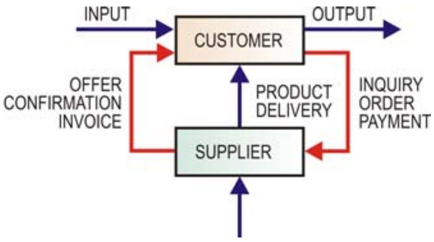

Figure 1: Customer/supplier business model.

The described model is commonly used in trading. It connects a supplier and a customer into a value chain where the first one delivers value which is captured by the second one. It results in a zero-sum game.

As such it is adequate for many businesses but the question here is if it is appropriate also for trading product-service systems where synergetic effects are searched for.

In order to point out specifics of the product-service systems in case of production equipment let us consider the issue from the customer view and from the supplier perspective. The customer is primary focused on products which he delivers just-in-time to his customer. Therefore, he requires not just a equipment supplier but a partner who would develop, manufacture, install, put the equipment into operations and, later on, who would offer support in operations in terms of process optimization, maintenance, spare part delivery, system improvement, upgrading, reconfiguration, etc. [5].

The suppliers' perspectives are discussed in [6]. The authors analyzed business models in project-based firms. There exist different solutions which suppliers of capital investment goods are offering to their customers - from simple equipment deliveries to full-scale turn-key deliveries. This exhibits flexibility of suppliers in adapting to customers requirements. The authors categorized the existing models into five types and discovered that the so called life-cycle-led solution utilizes synergies.

The way that leads to a win-win game is co-creation of value by interacting systems [7]. Therefore, the industrial product-service system business model should rely on collaboration among the main actors, i.e. a customer, an original equipment manufacturer (OEM) and its suppliers as well as service providers, in which the involved parties share the same goals. It should provide a joint offering of product and services covering the entire life-cycle of the production system enabling high performance of operations.

Based on these cognitions a product-service system business model is being conceptualized. It originates from the conceptual framework for collaborative design and operations of manufacturing work systems developed in [5]. The framework provides elements for collaboration of different parties in a network and introduces two distinct units (1) the virtual coordination unit (VCU) for coordination of collaboration among different experts from different cultural environments and (2) the virtual competence center (VCC) as a portal for communication, teamwork, and provision of information, knowledge and services. The product-service system business model proposed here extends the framework for collaborative design and operations toward product-service systems.

Figure 2 shows the structure, elements and actors of the product-service system business model and interrelations among them. It has a form of a value network. The network is established not only for a single business transaction but forms a lasting relationship. This is a significant advantage in comparison to the classic customer/supplier business model, which links companies in a value chain only for a single transaction.

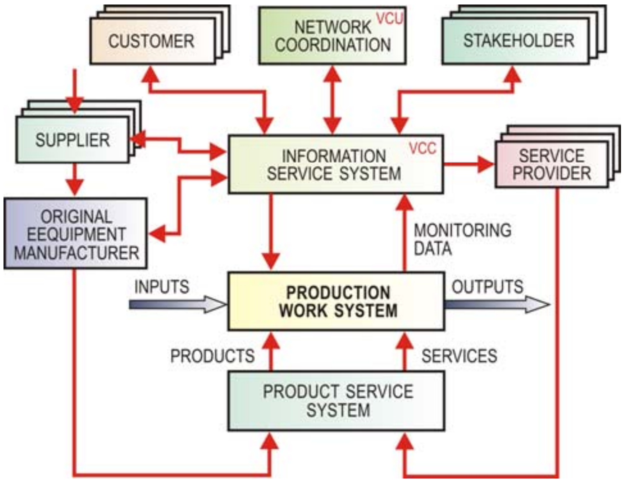

Figure 2: Value network of the product-service system business model.

Of course, the involved actors have to position themselves in the value network and have to adapt their business models to the new common goal of the network, which is enhanced performance of the target work system of the customer.

The expected benefits of the proposed model are lasting partnership and increased trust among the actors, value co-creation through collaboration with common objectives, coordinated and responsive problem solving, sharing of information, knowledge and risks, decreased transactional costs, etc. All this indicates the win-win game.

Now let us have a closer look on the value network model (Figure 2). In the center of the model is the production work system of the customer (user). This is the target element not only for the user, but also for the OEM and service providers, which jointly offer the product service system. Through the OEM also its suppliers are interconnected in the value network. They all share the common goal – to maximize value creation of the target work system. But each of them has its own position, role and responsibility in the network. Also the user customers are involved in the value network while they benefit from the improved production system performance. And there may be also other stakeholders which are related to or are interested in the production system operations from various aspects.

This research is focused on providing services during production system operations. During operations the common goal is optimal system performance resulting in high output generation, high operation reliability, high productivity and efficient utilization of resources, minimal operational costs, minimized environmental impact, etc. All actors of the value network require adequate and accurate information about the system states in order to be able to identify a need and to perform their role in the value network by providing an adequate service when required.

Implementation of services into complex industrial systems is possible only with the use of new communication and information technologies [8]. They enable cost effective and reliable monitoring and control of production equipment.

Therefore, the key issue of the research is how to provide on-line information on system operation and how to adjust information content to needs and responsibilities of each actor in the value network. Adequate service infrastructure has to be conceptualized and developed which will enable collecting of relevant data in the work system, management of these data and provision of relevant data in form of information services.

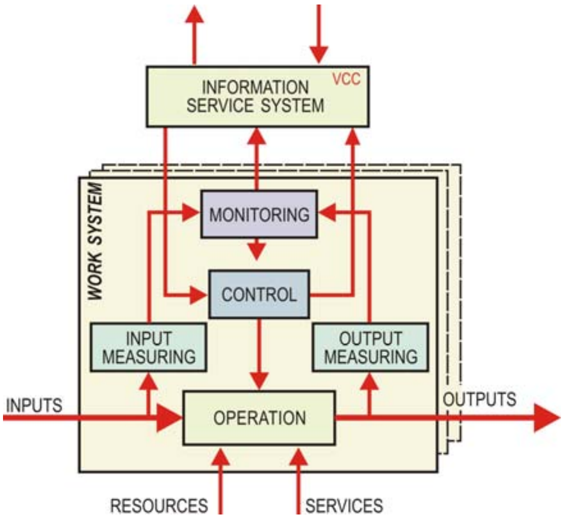

Figure 3: Service infrastructure of the value network.

An element of the proposed infrastructure is the information service system (ISS) as a part of the VCC portal introduced in [5], which provides information services related to system operations. The ISS in integrated in the value network (Figure 2).

Another part of the service infrastructure forms a system for monitoring production operations. Monitoring is performed by measuring different physical quantities band by collecting different signals in the production system, data acquisition and data management. Monitoring provides data on production processes, equipment states, and operations related events, quality state, state of the environment, etc. These data are inputs for the information service system. ISS provides information services which interpret monitoring data and are tailored to needs, responsibilities and access rights of actors and stakeholders. The infrastructure of the product-service value network is shown in Figure 3.

3 PRODUCT-SERVICE SYSTEM FOR SMALL HYDROPOWER PLANTS

Small hydropower plants (SHP) are a challenging industrial sector for the implementation of the product-service system concepts. They have similar structure as industrial power plants but they are less complex and therefore easier to handle and more feasible for implementing and testing of innovative solutions. On the other hand they represent a prospective market searching for solutions which may improve their performance. There are many opportunities and challenges for new developments in the sector.

For illustration, there are approximately 500 SHPs which operate in Slovenia, most of them ranging from 25 to 100 kW of output power. They provide about 12 % of electricity produced from renewable sources [9]. The majority of them were built in the 90-ties by private landowners. Building renewable energy plants was at that time encouraged by the government’s policy with subventions and bounties. Many of them are of rather simple design.

There are many actors and stakeholders in the sector which are not well connected. They would all benefit if they would be connected in the value networks. The main actors and stakeholders are electricity producing companies, plant operators, plant owners, electricity distributors (customers), manufacturers of equipment, maintenance providers, engineering companies, business associations, fishing associations, associations of ecological movements, governmental institutions, etc.

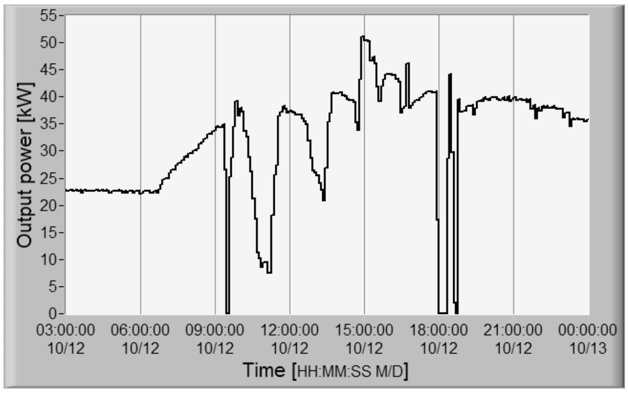

Figure 4: Power generation diagram.

Of course, the actors and stakeholders have different roles, interests and responsibilities in relation to operations of a power plant. It is a fact that they all have only limited or even no access to information from power plants which they need to fulfill their responsibilities and perform their work. Hence, they often have to collect information by themselves and they make their decisions on incomplete and inaccurate information. Each of them is searching for a solution which would deliver him relevant information when and where needed. For example, a plant operator is interested in operational performance monitoring, such as shown in Figure 4. He would prefer access to on-line monitoring from anywhere at any time to be able to see what is going on and to identify possible malfunctions. He would also prefer remote control for performing control actions on a distance and receiving of alarm messages in case of malfunctions. An owner would prefer periodic insight into economic figures, productivity, equipment utilization, etc. A maintenance provider would favor data on equipment behavior. A fishing association would prefer permanent monitoring of water level in a form as shown in Figure 5 and communication of warnings in case that the water level drops under the biological limit level.

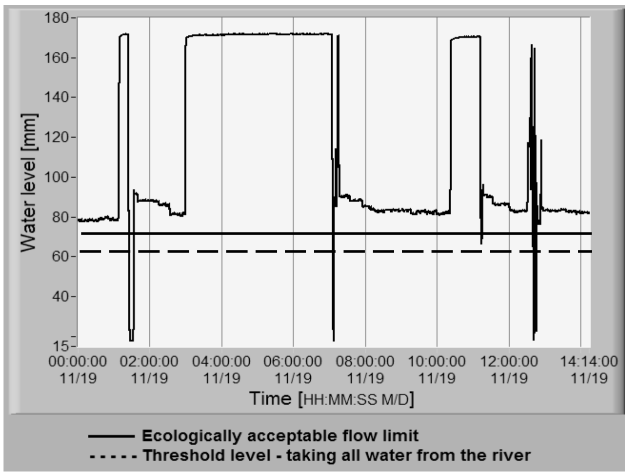

Figure 5: Water level diagram.

These observations clearly indicate what an adequate information service system based on the concept proposed in Chapter 2 providing tailored pieces of information in form of services would be a sound solution for most of actors and stakeholders.

In order to identify more precisely needs and requirements for developing an appropriate ISS for supporting SHP operations an empirical survey was conducted. The survey was focused on private SHPs in Slovenia and 86 SHP operators and/or owners participated in it.

The main focus of the survey was related to SHP management, monitoring, control and maintenance. Some of the figures are given in next. More results are given in [8].

Most of the SHPs (61%) are observed and controlled manually. Other operators use different systems for monitoring, alarming and control. In the case of stable conditions, operators visit SHP once or twice per day in average. A few operators visit SHP even more than three times a day and some only once in a week.

The major cause of SHPs breakdowns is sudden cut off from the electric grid. In average it happens about 5-15 times in a year. Most of operators (80%) confront problems of clogging a turbine and/or an intake grate with leaves and branches.

SHPs are out of operation several times in a year due to high or low water, and maintenance on the electricity grid or other systems.

Operators consider output electric power as the most valuable information for monitoring operation performance. The second most important parameter is the water level in a river. On this basis the operator sets the guide vane ring angle and consequently energy production.

Operators recognize SMS alarming of critical operational states as the most important functionality of the information service system. Automatic control of guide vanes position according to the actual water level is the second most important functionality. Live video stream from a power house and from a dam are the least preferred functionalities.

Another important issue which motivates this research is related to control of SHPs. As already mentioned, the most of SHPs are of rather simple design. This implies that the level of automation is low and most of SHPs are controlled manually. But this does not imply permanent presence of a human in a power plant while there are safety systems which react independently in abnormal situations.

In case of a normal situation (e.g. stable water flow) the manual control is performed like this. An operator occasionally visits a plant, typically located in remote, hardly accessible areas, and visually inspects various states and parameters, such as dam water level, output electric power, bearings temperature, vibrations. Based on the identified state, he sets a reference value for control manually. He manipulates guide vanes opening according to head, energy production and assurance of ecologically acceptable water flow in a river bed. Then, the plant runs according to this setting until he inspects it again. During this interval the situation on the plant may change. For example, it can happen that the power plant is cut out from the electricity grid. It happens in case of a sudden hazardous event, when the safety system must disconnect the generator from the grid and stop the turbine. Hazardous events may happen due to short-circuit in the power grid as a result of ice or snow on electrical wires, strong wind or fallen trees on electrical wires, etc. In such cases the plant may be out of operation for hours or days till the operator's manual intervention.

It is evident that such control is not adequate. Especially information about generator cut off, and about excess or shortage of water on a dam are critical. Magnitude of water flow, which can be used in a power-plant depends on actual water flow, water temperature, season, etc., and is governed by ecological considerations and jurisdiction. The mentioned problems and challenges motivated the decision about developing an information service system for remote monitoring, alarming and control of a SHP. The objective was to improve operational performance of SHP operations. The system is realized as a modular information service system for remote and mobile monitoring and control and is implemented on a SHP in Slovenia. The pilot implementation is described in next.

4 SHP INFORMATION SERVICE SYSTEM FOR REMOTE AND MOBILE USERS

The basic objective of the SHP information service system is to provide the following remote and mobile services to operators and other stakeholders concerned in safe and efficient SHP operations: (1) operation monitoring, (2) activation and deactivation of the plant, (3) guide vanes manipulation, and (4) alarming about abnormal and critical situations.

The developed system is implemented as a functional prototype of the information service system in SHP "Volaka" [10], which uses a Francis type turbine with nominal output power of 70 kW. The information service system consists of the following units:

- Data acquisition system with sensors and signal processing for collecting data about key operational parameters;
- Control loops for plant activation/deactivation and manipulation of the guide vane opening;
- On-site control and monitoring system based on a pc with control software, database and internet server;
- Web application for remote and mobile users;
- Short message service (SMS) module for alarms; and
- Mobile communication network.

The mobile communication is selected because a broadband connection is usually not available on SHP sites and because it suits better mobile users and enables around-the-clock availability which is needed during 24/7 plant operations.

Figure 6 shows the semi-operational scheme of the information service system integrated in a small hydro power plant.

Several plant operational parameters, e.g. output power (Figure 4), dam water level (Figure 5), guide vanes position, temperatures of critical elements and generator frequency, are constantly measured and monitored. The acquired data are logged into the database and enable visualization of an actual situation and elaboration of periodical reports, invoices for customers, etc.

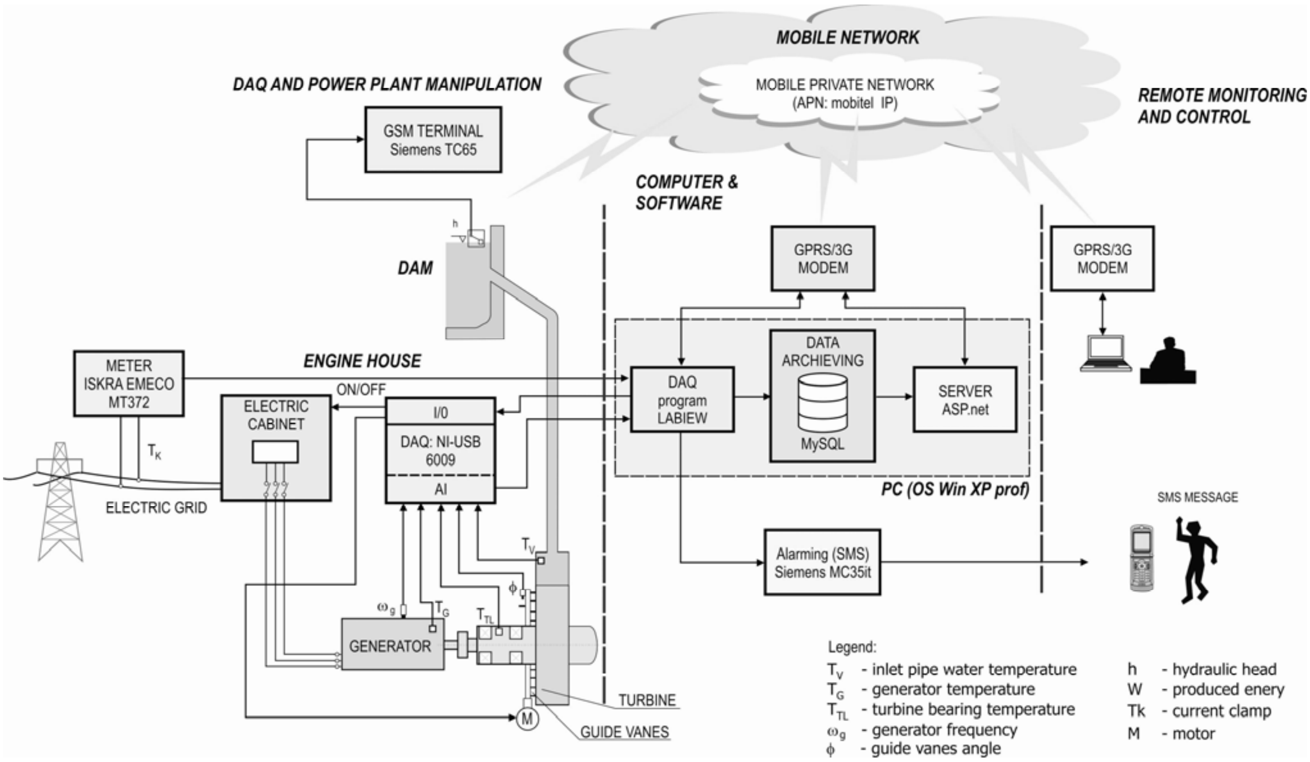

Figure 6: Semi-operational scheme of the information service system.

Measurement of output power and produced electric energy is the basic information on power-plant operation. The output power depends on the flow and dam water level. Power readings are acquired from a digital power meter periodically. Any deviation in operations (e.g. generator speed increase, power loss, water level fall) is reflected in this measurement and results in a corresponding control action and/or triggering of an alarm message to the operator.

Three functionalities are enabled for remote users: plant monitoring, remote control and access to the database. A remotely located operator connects with a laptop computer to the mobile network and logs onto a mobile private network within the public one. The mobile private network interconnects the SHP control and monitoring system with remote users. The crucial advantage of the mobile network lies in its ubiquitous signal. Business users are entitled to communicate business data with a safe private mobile IP network. Inside such a private network communication between any particular SIM card is possible anytime anywhere. An APN (access point number) and a password are assigned to the user, and each SIM card obtains its own IP address. The communication is safe and speed acceptable.

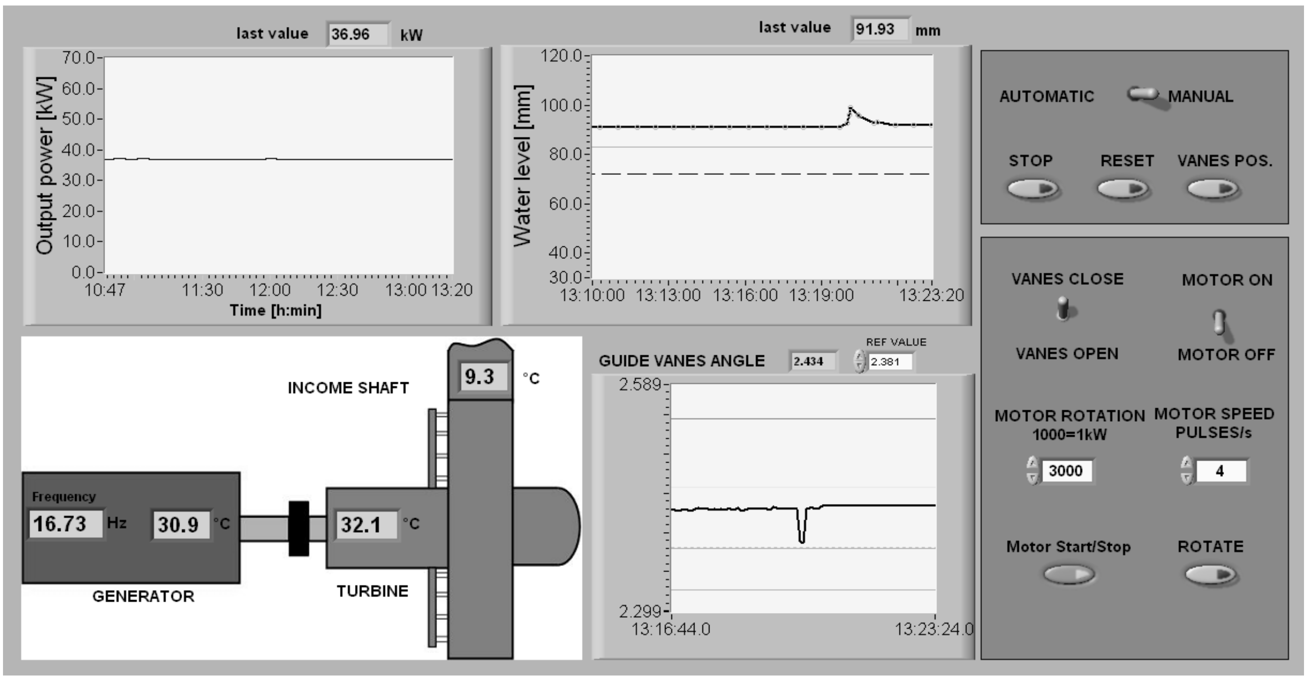

Figure 7: Web application for monitoring SHP operations.

Once connected, the operator can access to the SHP via a web application. This application enables him to view the monitoring data and to trigger the appropriate control actions when necessary. Figure 7 shows a typical screenshot of the application.

The described remote service system has been in operation for several months. During this time the following advantages have been identified:

- Energy production is increased for about 5 % in average.
- Sensing of selected operations parameters improves the insight in the SHP, which makes its operation and maintenance more straightforward.
- Remote monitoring and control facilitates operator's work.
- Increased equipment utilization.
- Flexible system design enables easy adoption of the system.
- Alarm messaging is automatic and prompt.
- Database offers numerous reporting possibilities and automation of various functions.
- Better control of water flow due to prompt water level observation and remote control of guide vanes.
- Moderate communication costs and adequate security.
- Reliable operations of the monitoring system.

5 CONCLUSION

In the contribution an approach toward a new product-service system business model for production equipment is discussed. The kernel of the model represents the value network, which enables partnership and collaboration among a customer, OEM, suppliers and service providers, and is focused on production performance and equipment utilization by providing products and related services

It is expected that due to synergetic effects of collaboration, better equipment utilization could be achieved and thus additional value created and fairly shared among partners.

The business model integrates an information service system, which supports all actors and other stakeholders with information services related to production system operations and tailored to the individual needs and responsibilities. The adequate infrastructural elements are introduced and integrated in the value network.

The pilot information service system 'Volaka' is developed and implemented on a small hydropower plant. It enables remote and mobile access to the on-line monitoring system of the power plant, alarming of operators in case of malfunctions and triggering of control actions.

For the communication backbone the mobile network is selected due to the ubiquitous signal reach. This is a significant advantage in case of SHPs, which production sites are usually in remote and hardly accessible locations.

The pilot system clearly exhibits economical, technical, social and ecological benefits of integrating products and services.

The knowledge gained in this research will be used and further developed in the newly proposed EUREKA project E! 5343 "Collaborative platform for operations support of work systems – case of hydro power plants". The project consortium is composed of six partners from three European countries: two OEM providers of equipment for hydropower plants, one service provider with competence in measurement of dynamic quantities and diagnostics, one software provider for supporting collaboration, one operations and maintenance provider and agent of a customer and an academic institution. The major aims of the project are to research the issue of relationship between customers and suppliers of production equipment and to develop a new business model of this customer/supplier partnership and adequate services related to support of equipment operations and maintenance. That would significantly improve the equipment utilization and contribute to competitiveness of customers, OEMs and service providers.

6 ACKNOWLEDGMENTS

This work was partially supported by the Slovene Ministry of Higher Education, Science and Technology, Grant No. P2 0270 and Grant No. 1000-09-310150.

7 REFERENCES

[1] Goedkoop M., van Halen C., te Riele H., Rommens P., 1999, Product Service Systems, Ecological & Economical Basics, Pre Consultants, The Netherlands.

[2] Meier H., 2009, Industrial Product-Service Systems IPS2, IPS² Spring School, Cranfield, February 2009.

[3] Meier H., Massberg W., 2004, Life Cycle-Based Service Design for Innovative Business Models, CIRP Annals - Manufacturing Technology 53/1: 393-396.

[4] Meier H., Roy R., Seliger G., 2010, Industrial Product Service Systems – IPS2, CIRP Annals - Manufacturing Technology, 59/2, to be published.

[5] Sluga A., Butala P., Peklenik J., 2005, A Conceptual Framework for Collaborative Design and Operations of Manufacturing Systems, CIRP Annals - Manufacturing Technology, 54/1:437-440.

[6] Kujala S., Artto K., Aalonen P., Turkulainen V., 2009, Business model in project-based firms – Towards a typology of solution-specific business models. Int. J Project Management, in press.

[7] Ueda K., Takenaka T., Vanza J., Monostori L., 2009, Value creation and decision making in sustainable society, CIRP Annals - Manufacturing Technology, 58/2: 681-700.

[8] Selak L., Sluga A., 2009, Mobile control of a small hydropower plant (in Slovene), Ventil, 15/3: 240-245.

[9] Slovenian small hydro power association, Available from: http://www.zdmhe.si/, Accessed: 2009-09-24.

[10] Selak L., Sluga A.. Butala, P., 2009, Mobile Monitoring of Small Hydropower Plants. In: Katalinic B. (Ed.); Annals of DAAAM for 2009 & Proceedings of the 20th International DAAAM Symposium, Vienna, Austria:1795-1797.