Small ORC (Organic Rankine Cycle) Power Units for Remote Applications

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Abstract: Over the last 45 years, the development of backbone telecommunications systems and construction of strategic oil and gas pipelines has spanned tens of thousands of kilometres in harsh environments (arctic to tropical, unmanned or developing areas). As the vast majority of these areas are without an electrical power lines infrastructure, the need arose for a highly reliable and maintenance-free power supply to allow the continuous operations of these projects. ORC (Organic Rankine Cycle) based on CCVT (closed cycle vapor turbogenerator) was specially developed for the special requirements. The paper presents the CCVT and its mode of operation, design criteria and case studies in projects implemented in the last 45 years.

Keywords: ORC, CCVT, reliability, MTBF, remote.

1. Introduction

The objectives for high reliability in telecommunications, cathodic protection and SCADA (supervisory control and data acquisition) systems in strategic projects have become very demanding, and the problems faced by power systems designers in areas not serviced by commercial power are very stringent, since power generators must operate continuously on a 24-hour-per-day, 365-day-per-year basis.

Modern solid state electronic equipment requires relatively low power (from a few hundred watts to 4 kW) but stringent requirements for power supply: high reliability, long life (over 20 years) and low maintenance. Conventional diesel generators were not adequate. Intensive research followed in the development and application of sophisticated energy converters with attention directed to practical units. Two technologies emerged: the TEG (thermoelectric generator) and the CCVT (closed cycle vapor turbogenerator). Both are widely used: TEG below 1 kW and CCVT from 600 W to 4 kW. PV (photovoltaic) systems were introduced lately but are hindered by vandalism and theft (unattended sites). Fuel cells have a too short life-span, at least for now.

2. Background

The Ormat ORC (Organic Rankine Cycle) power unit was originally part of a program related to the harnessing of solar energy started in 1958. Conversion of solar heat into power needed a heat engine to operate at low temperatures (below 200 °C/392 °F).

There were no suitable prime movers for these low temperatures and small sizes. The steam turbines or steam engines available were almost useless with these limitations, and gas and hot air engines were entirely inapplicable.

To achieve especially long life and avoid mechanical and thermal stress, it was necessary to develop a heat engine that would operate at comparatively low temperatures (below 200 °C/392 °F). To accommodate these low temperatures and small sizes, it was decided to design a prime mover, based on a Rankine cycle, specifically for the applications in mind. A turbine rather than a reciprocating engine was chosen, and
steam was replaced by other working fluids selected and tested for stability. Criteria for the selection of optimum working were established [1].

The turbine has been designed to be as reliable and maintenance-free as possible. 300 W hermetically sealed solar and fuel fired prototypes were operated in 1964. In 1966, after work on process fluid lubricated bearings and hermetically sealed systems, the first hermetically sealed solar and fuel operated systems operated. The inherent high reliability and low maintenance units opened an application field for fossil fuel-fired units for on-site power generation in remote locations and the first unit has been followed by some 3,000 fuel operated units rated 400 W to 4 kW. These CCVTs have logged more than 50 million field operational hours, and many units have been in operation for over 35 years without overhaul with a field proven MTBCF (mean time between critical failures) of over 200,000 h for the turbogenerator itself, demonstrating the technical viability for this concept.

3. Design Criteria

The CCVT is a Rankine cycle hermetically sealed turbogenerator having one smoothly rotating moving part. Turbine in lieu of a reciprocating engine was a decision based on operating and efficiency considerations.

The criteria for selecting the working fluid [2] are:
- molecular weight (high, well over 100);
- boiling point (in the range of 100-200 °C);
- T-S diagram characteristics;
- stability over many years of operation. Thermal stability is, in fact, the first criterion in choosing a working fluid.

Monochlorobenzene more or less satisfies these requirements.

CCVT is adaptable to a wide range of heat sources including natural gas, liquid petroleum gases, liquid fuels, etc., and operates many years for 24 hours/day, 365 days/year.

4. CCVT

The CCVT consists of a combustion system, a vapor generator, a turboalternator, an air-cooled condenser and a rectifier. Fig. 1 shows a cutaway of the CCVT.

The CCVT utilizes a hermetically sealed Rankine cycle generating set which contains only one smoothly rotating part, the shaft, on which the turbine wheel and brushless alternator rotor are mounted. The turboalternator shaft is supported by a “working fluid film” bearing lubricant, which eliminates any metal-to-metal contact, thus, providing years of maintenance-free, trouble-free operation.

The fluid cycle is closed and requires only the application of external heat, for continuous production of power. Natural gas typed from the pipeline is an ideal fuel for the CCVT. Because of its purity, liquefied petroleum gas is often chosen as a desirable fuel for typical arctic applications.

The CCVT is a fully integrated and tested power system that can provide from 400 W to 4,000 of filtered DC (direct current) power on a continuous basis for 30 years or more, with minimal maintenance. It includes the self-contained power package, along with an alarm and control module, housed in a shelter.

The CCVT operates as follows (see Fig. 1). The burner heats the organic fluid in the vapor generator where some of it vaporizes and expands through a turbine wheel to produce shaft power to drive the alternator. The vapor then passes into a condenser where it is cooled and condensed back into the liquid state. The liquid passes back into the vapor generator, cooling the alternator on its way and lubricating the bearings. The cycle continues as long as heat is applied to the vapor generator. Because the liquid/vapor stainless steel canister is sealed, none of the organic fluid is lost in the process. Furthermore, the working fluid is totally immune to climatic conditions outside the sealed canister [3].

The turboalternator produces three-phase AC (alternating current) power, which is rectified and filtered. The standard output is 24 or 48 or 110 volts
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DC. Other DC voltages and auxiliary AC can be made available through the appropriate use of converters and inverters in the system. A digital turbine control unit controls the CCVT system (see Fig. 2).

Safety controls protect against any abnormalities and malfunctions, including overheating. Because of the low operating pressure and temperature of the system, personnel safety is assured.

The output voltage is regulated by controlling the amount of fuel, which flows to the burner. This is accomplished by a pre-set upper and lower voltage sensing circuit, which monitors the output DC voltage
and, in turn, closes or opens a fuel valve.

5. Field Experience with CCVT

Over the last 45 years, CCVTs have been deployed in numerous applications in the oil and gas industry along pipelines and on offshore platforms. These power systems provide DC power for a wide variety of equipment including telecommunications networks, telemetry and SCADA systems, pipeline cathodic protection systems, motorized valve controls, navigational aids and remote emergency lighting. CCVTs have also been powering telecommunication applications, including repeater stations, telecommunications links and fiber optics sites in Antarctica, North America, South America (Andes Mountains and Patagonia), Western and Northern Siberia, Far East of Russia and Kazakhstan.

5.1 Trans-Alaska Pipeline Case History

Since 1976, 122 CCVTs, rated at 600 W, have powered the RGV (remote gate valve) stations along the trans-Alaska pipeline. These RGV stations operate along 800 miles of the pipeline, which has transported over 11 billion barrels of crude oil. After their first 20 years of operation, the pipeline operator, Alyeska Pipeline Service Company, noted, “the energy converters have been operating at reliability levels above the manufacturer’s specifications since their installation (and) are still providing dependable power. Not even one single station power outage has been observed [4].”

The RGV station includes the gate valve, communications and control equipment, a battery bank as well as the CCVT and the fuel tanks. In addition to powering the gate valve and communications, control and supervisory equipment, the CCVT also maintains the float voltage on the battery bank. The integrated power module includes two propane fired CCVTs, a non-electric heating system for the equipment shelter and the distribution and control equipment, which is deployed in the incredibly harsh Alaskan winter environment (with temperatures falling to \(-60 ^\circ C/\sim76 ^\circ F\) in the winter with snow loads to 90 psi). To assure peak performance of the overall system, the entire power solution, including the CCVTs, the main shelter, the heating system and related equipment, was manufactured and integrated by Ormat. In this pristine, extremely harsh environment, one of the key concerns of the pipeline operator is to preserve the environment and minimize the potential for oil spills. These remote gate valves play a critical role in preventing oil spills.

Today, CCVTs, originally designed for twenty years of service, are still in operation, exceeding design objectives by more than eighteen years (see Fig. 3).

After more than 30 years of continuous and successful operation of CCVTs along the trans-Alaska pipeline, the project operators, Alyeska Pipeline Services, decided to upgrade and replace the telecommunications/RTU (Remote Telecommunication Unit)/SCADA equipment in the RGV stations with new generation equipment that requires almost double the power than that of the original equipment. As a result, the capacity of the batteries in the stations had to be increased, and, in turn, it was necessary to increase the CCVT power from 600 W to 1,200 W.

Alyeska Pipeline Services requested Ormat to replace the old CCVTs with new units absolutely keeping the same mechanical and electrical interface between the CCVTs and the equipment shelter as in the original project, in order to avoid the expense of redesigning and installation of new infrastructure that would have been required otherwise.

In the Alaska project, to ensure that the mechanical and electrical interface between the new higher capacity CCVTs and the existing equipment shelter that would be the same as in the original project, and a pilot station was ordered and put into operation in 2007. The entire mechanical and electrical interface was tested in operation to the satisfaction of Alyeska Pipeline Services, and, as a result, they have recently
started a program of gradually replacing over a period of several years, the old CCVTs, still operating since 1975, with the new 1,200 W CCVT units. Fig. 4 shows the installation of the new 1,200 W CCVT units in one of the Trans Alaska RGV stations.

Gazprom Gas Pipelines Network: Gazprom’s experience with CCVTs has been equally successful. Gazprom is one of the largest natural gas production and transmission companies in the world and operates over 30,000 km of pipeline stretching from Siberia to Europe. The Russian winters are very harsh and the stations may be inaccessible for months; temperatures may reach as low as -60 °C/-76 °F for extended periods in winter and as high as +40 °C/+104 °F in the summer months. However, the telecommunications, cathodic protection and control stations must operate without maintenance support during this period. After a careful analysis of all the available power solutions
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(e.g., solar, wind, thermoelectric generators, and conventional electric generators), the CCVT was selected as the only approved power solution for these applications.

5.2 Gazprom Gas Pipeline Network

The reliability of CCVTs is confirmed by long-term experience of their application. In Russia alone, approximately 1,000 CCVTs of various capacities rated from 400 to 4,000 W are installed (see Fig. 5), along such projects as the gas pipelines providing gas to Europe, Urengoy-Uzhgorod and Yamal. Among them, 75 units are in operation for more than 30 years, (some since 1975), with the MTBF (mean time between failures) being equal to 80,000 h (according to customer records, a number of CCVTs have each reached MTBF of 245,280 h). Only 13 failures were recorded throughout all the operating period. The proven, recorded MTBCF is no less than 300,000 h. Frequency of CCVTs maintenance services is no more than once a year. Gazprom has found them to be field-proven as dependable and cost effective, both in terms of fuel consumption and maintenance expenses [5].

Recently, more than 130 CCVTs have been installed for new gas pipeline projects in Kamchatka (Fig. 6) and in the Far East of Russia (Sakhalin-Khabarovsk-Vladivostok).

5.3 Power Solutions for the Sakhalin II Project

The Sakhalin II project is one of the most important pipeline projects built in the last 20 years. It consisted in the development of two offshore fields in the Sea of Okhotsk approximately 20 km to the east of the Sakhalin Island coast, known as the Piltun-Astokhskoye field and the Lunskoye field. The development of the Piltun-Astokhskoye field concerns oil and gas production, whereas, the Lunskoye field is predominantly a gas and condensate reservoir with potential oil rim development.

The pipeline systems are buried and the design life for the pipelines and related systems and accessories is 30 years.
Environmental conditions are typical difficult arctic.

Ambient temperature is between -39 °C/-39 °F and +37 °C/+97 °F, with 192 days with mean average temperature below 0 °C/+32 °F. The relative humidity is high throughout the year, the annual average being 80% and 89%. The maximum thickness of snow in the cold period is 135 cm, with an average of 47 cm. Snowstorms are frequent and there are 40-70 days with snowstorms/year with duration of up to 870 h.

Average wind velocity is up to 30 m/s, with gusts up to 44 m/s. The Sakhalin Island is known for its strong earthquakes. The seismicity, in accordance with SNIP II-7-81 is nine points (Destructive) on MSK-64 scale.

The oil and gas dual onshore pipeline traverses 126 km of swamp crossings, 110 km of mountainous routes, more than 1,000 rivers, 18 rails and ten road crossings. Large sections of the pipeline are located in remote arctic areas that are difficult, sometimes impossible, to access at certain times of the year.

Electric power is required at the offshore and onshore facilities as well as the 102 unattended locations along the pipelines. Because of the considerable distances involved, an integrated electrical supply system would not be economical. SEIC (Sakhalin Energy Investment Company) needed a remote power solution with a proven track record of reliability in extremely cold climates as well as predictable annual maintenance schedule. Because of the difficulty in sending supplies, it was important to use the fuel from the pipeline, which would require gas pressure reducing systems.

For 102 unattended locations requiring power, in accordance to the project specifications, Ormat was selected to provide 102 remote EPSs (energy power systems) for the pipeline, based on highly reliable, single low maintenance power generation units with battery back-up were installed. These power generation units are used to power cathodic protection, SCADA, remotely operated valves, and telecommunication equipment along the pipeline route. For this important task on such a strategic project, CCVT operated with gas from the gas export pipelines has been selected. At the unattended locations, the batteries are only used as back-up power supply for the period that the power generators are out of service.

Each EPS consists of one 4-kW CCVT and a specialized arctic equipment shelter to house the rest of the equipment.

For the Sakhalin II project, Ormat provided a total project solution of supplying the totality of the equipment required in the remote stations (see Fig. 7).
The EPS comprises, besides the CCVT and the arctic equipment shelter, the following:

- gas pressure reducing skid to enable use of gas from the pipeline;
- cathodic protection modules;
- VRLA (valve-regulated lead acid) battery bank to enable a 24-h backup;
- non-electrical heating system that uses residual heat from the turbogenerator;
- telecom and RTU equipment to enable remote monitoring;
- power distribution panels and switchgears, to support 110 VDC (voltage-to-digital converter), 48 VDC and 24 VDC;
- automatic certified fire detection and extinguishing system;
- heating and ventilation system;
- inverters, DC-DC converters;
- MCCs (Motor Control Centers) for operation of remote gate valves;
- stairs and walk-way for accessing CCVT and equipment shelter in all weather conditions;
- portable 3 kW diesel generators for black-start of remote stations.

As the pipelines went into production, EPS ensure continuous, reliable pipeline operation throughout the coldest months of the year.

## 5.4 Power Solutions for Kazakhstan-China Gas Pipeline Project

For the Phase II of the Kazakhstan-China gas pipeline project, integrated power systems consisting of CCVTs and arctic shelters similar to those in the Sakhalin II projects have been supplied and are actually under commissioning and start-up.

Twelve EPS consist of two redundant 2-kW CCVTs and a specialized arctic equipment shelter to house the rest of the equipment.

Distribution voltage for the unattended locations is 48 VDC. For electrical equipment installed in the stations that cannot operate at this voltage level, DC-DC converters are used to convert this 48 VDC to the appropriate voltage level, 24 VDC. Inverters are used for electrical equipment operating at 220 VAC.

Distribution voltage for the unattended locations is 48 VDC. For electrical equipment installed in the stations that cannot operate at this voltage level, DC-DC converters are used to convert this 48 VDC to the appropriate voltage level, 24 VDC. Inverters are used for electrical equipment operating at 220 VAC.
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The EPS comprise (see Fig. 8), besides the CCVT and the arctic equipment shelter, the following:

- gas pressure reducing skid to enable use of gas from the pipeline; VRLA battery bank to enable a 24 h backup;
- non-electrical heating system that uses residual heat from the turbogenerator;
- telecom and RTU equipment to enable remote monitoring;
- power distribution panel, to support 220 VAC, 48 VDC and 24 VDC;
- automatic certified fire detection and extinguishing system;
- heating and ventilation system;
- inverters, DC-DC converters.

6. Conclusions

Reliability and availability of power supply in remote stations are paramount factors for pipeline operation and its revenues. Selection of the most reliable power units and adequate redundancy are also extremely important factors. CCVTs have been deployed with great success in a wide variety of applications in various configurations to provide reliable and economical power at remote operating sites. With over 45 years of field experience, CCVT technology is proven to be highly reliable in the most adverse of environments. In addition, CCVTs have proven to be environmentally friendly and economical to deploy. CCVTs are very suitable for mission-critical applications where performance and reliability are important.

References