LEVERAGING THE LEDA HIGH VOLTAGE POWER SUPPLY SYSTEMS FOR THE LANSCE REFURBISHMENT PROJECT*

J. Bradley III, D. Rees, W. Roybal, K. A. Young, LANL, Los Alamos, NM 87545, U.S.A.

Abstract

The LANSCE Refurbishment Project (LANSCE-R) will revitalize the LANSCE accelerator infrastructure. Much of the equipment has been in use for over 39 years and is approaching the end of its design lifetime. As obsolescence issues make like-for-like replacements increasingly more expensive, modern systems with lower costs become a reasonable alternative. As part of the LANSCE-R project, four of the seven HV power supplies for the 805 MHz RF klystrons will be replaced. The present and future requirements for these power supplies influence the selection of replacement options. Details of the HV power supply replacement requirements and the different replacement options will be discussed. One option is to use four 95 kV, 21 A DC power supplies originally installed nearby as part of the Low Energy Demonstration Accelerator (LEDA) project. Significant material and labor cost savings can be achieved by leaving these supplies installed where they are and building a HV transport system to bring high voltage power from the existing LEDA facility to the LANSCE facility. The different replacement options will be compared based on material and labor costs as offset by long-term energy savings.

OVERVIEW OF THE EXISTING LANSCE HVPS SYSTEMS

The LANSCE facility uses seven sectors of 805 MHz klystrons to drive a side coupled 800-MeV proton linac capable of delivering up to 800 kW of beam power. The klystrons require pulsed High Voltage (HV) DC power to operate. The High Voltage Power Supply (HVPS) systems regulate the incoming AC power and convert it to regulated HV DC power. Each sector has a HVPS located just outside the north wall of the klystron gallery and a capacitor room located within the klystron gallery. Underground HV cables transmit the power from the HVPS system to the capacitor room. All of the klystron modulators in a sector draw pulsed HV DC power from that sector's capacitor room.

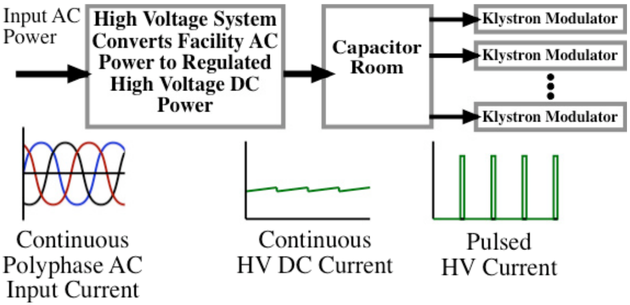

Figure 1: HV System Overview.

Fig 1 diagrams the power flow in the HV system. When the klystron modulators are pulsed on, the peak klystron beam current is provided by the charge stored within the capacitor bank. During the interpulse period when the klystrons are off, the HVPS system recharges the capacitor bank to the nominal 85 kV level.

The existing LANSCE HVPS systems consist of two sub units: an Inductrol® Voltage Regulator (IVR) and a HV step-up Transformer/Rectifier (T/R). The IVR can vary the three phase 4160VAC input power by ±33%. The output of the IVR feeds T/R. Adjustment of the IVR varies the T/R output voltage from 47 to 90 kV. The standard IVR and T/R sub units are both oil filled devices and are shown in Fig 2 . The existing HVPS systems for the seven sectors (B-H) at LANSCE were installed during the late 1960s and early 1970s.

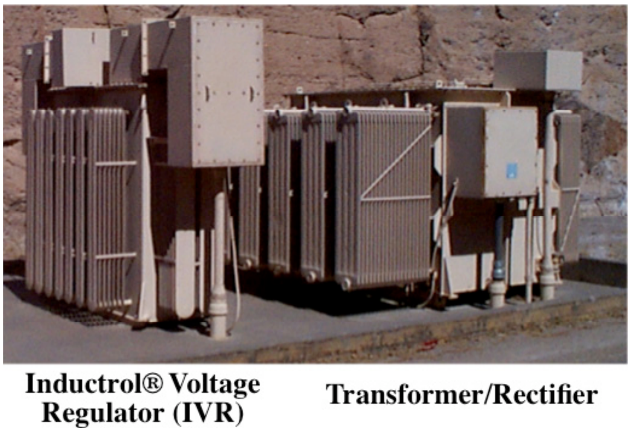

Figure 2: IVR and T/R sub units in the existing LANSCE HVPS systems.

NEED FOR HVPS REPLACEMENT

The LANSCE HVPS systems are in excess of 30 years old and it is well known in the literature that systems of this age are approaching end of life [1]. Dissolved gas analysis has been adopted as a tool for assessing the status of the LANSCE HVPS systems. The transformer oil is typically sampled on a yearly prior to any reprocessing (cleaning). Because the level of dissolved gases in the oil and the gas evolution within the transformers varies with hours of operation and operating parameters, we use the level of dissolved gas not as an absolute quantitative indicator of health but as a qualitative indicator of which units are experiencing the highest level of age related degradation. The status of the LANSCE HVPS systems is inferred from the dissolved gases within the oil in accordance with the following list [2]:

- Methane, Ethane, Ethylene, and Hydrogen are produced from high temperature thermal heating of oil.

---

*Work supported by the NNSA, U. S. Department of Energy under contract DE-AC52-06NA25396.

- Acetylene is produced only at the very high temperatures that occur in the presence of an arc.
- CO_2 is produced from low temperature thermal degradation of cellulose products.
- CO is produced from high temperature thermal degradation of cellulose products.

IEEE standard C57.104-1991 establishes recommended limits for the types of gases found in the LANSCE transformers. These limits are 2500 ppm for CO_2, 350 ppm for CO, 50 ppm for Ethylene and 35 ppm for Acetylene [3]. Table 1 shows how the measured values compare to the IEEE standard. This data indicates thermal degradation of cellulose products in the transformers for Sectors B, D, E and G. Ethylene indicates high temperature heating in Sectors B and E. Acetylene in Sector F transformer indicates arcing may be indicated. Based on the results of the analysis, a minimum of 4 units should be replaced.

Table 1: Existing LANSCE HVPS in FY 2004.

Location	Gas-in-oil in ppm and Analysis
Sector B	CO_2 – 8986, CO – 367, Ethylene – 59. CO_2 , CO, and Ethylene above IEEE limit.
Sector C	All gas levels good.
Sector D	CO_2 – 3897, CO – 247. CO_2 above IEEE limit.
Sector E	CO_2 – 10607, CO – 440, Ethylene – 109. CO_2 , CO, and Ethylene above IEEE limit.
Sector F	Acetylene – 84
Sector G	CO_2 – 4323, CO – 229. CO_2 above IEEE limit.
Sector H	All gas levels good.

HIGH EFFICIENCY KLYSTRON ENERGY SAVINGS

New high efficiency klystrons have been developed in the four decades years since the first LANSCE klystrons were designed. These high efficiency klystrons increase the RF-to-DC conversion efficiency from approximately 40% with the existing klystrons to approximately 65% with the new klystrons. This will decrease the amount of AC power required to produce the RF power delivered to the cavities by roughly 40%, reducing the four sectors' electricity costs by approximately $650k (US$) per year.

The klystrons will be modulating anode klystrons operating at a maximum cathode voltage of 95 kV, a nominal peak RF output of 1.2 MW, and a nominal duty factor of 10% (120 Hz RF pulse train with 800 microsecond pulses). In order for the klystrons to achieve high efficiency at the LANSCE-R peak power requirement, the HVPS nominal system voltage must be increased from the present 85 kV to 95 kV.

HVPS REPLACEMENT OPTIONS

The high voltage systems represent the single most expensive component of the LANSCE-RF systems. Four options were considered. The first two options involved the procurement of new HVPS systems. The last two options involved the use of existing HVPS systems left over from a recent project.

Procure New HVPS Options

The first option was replacing the old LANSCE HVPS systems with nearly identical units that could produce the required 95 kV. This option is not viable because not only are the units no longer made by their original manufacturers, but the entire technology of controlling voltage with megawatt sized mechanical variable inductors (Inductrol®s) is obsolete. The risks would include re-engineering old technology that will not be supported in the future.

The second option was to replace the old LANSCE HVPS systems with modern SCR controlled HVPS systems that could produce the required 95 kV. The cost of removing the old systems would be added to the cost of building and installing the new systems. This made removing the old systems and replacing them with the latest technology less cost effective.

Utilize LEDA HVPS Options

Four new SCR controlled HVPS systems were installed across the street from the LANSCE accelerator as part of the Low Energy Demonstration Accelerator (LEDA) that was a part of the Accelerator Production of Tritium (APT) program in the mid 1990's. Table 2 shows how the LEDA HVPS systems are of similar output power ratings to the original LANSCE HVPS systems. While the total output power of the LEDA HVPS systems is less than the output power of the original LANCSE HVPS systems, the increased efficiency of the 95 kV klystrons allows us to generate the same RF power with the lower DC current.

Table 2: Comparison of Original LANSCE HVPS Systems and LEDA HVPS Systems.

Parameter	HVPS System	
	Old LANSCE HVPS	New LEDA HVPS
Max Output Voltage (kV)	90	95
Max Output Current (A)	26	21
Max HV Output Power (MW)	2.34	2.00

The third option was to uninstall the four new LEDA HVPS systems and move them to the unit substations north of the accelerator where the old LANSCE HVPS systems were installed. This is impractical given that the old LANSCE HVPS systems required three-phase 4160V input power feeds and the LEDA HVPS systems require six-phase 1500V input power feeds. The facility transformers to convert three-phase power to six-phase power are extremely large, so it is not economical to move these transformers across the street to the LANSCE accelerator. In addition, the cost of removing the old systems would be added to the cost of installing the new systems.

The fourth option was to leave the four LEDA HVPS systems in place and run HV cables under the road to the klystron galleries 50 meters to the north, as shown in Fig 3. This allows the existing hardware to be reused without the cost of moving it or relocating the input power feeds. The original LANSCE HVPS system could be left in place to serve as a backup system, eliminating the cost of disposal and offering an opportunity for improving reliability through redundancy. The reduced costs allows us to make more of an impact towards addressing other obsolescence and reliability issues within the LANSCE complex. For these reasons we chose the fourth option.

Figure 3: HV cable routing from LEDA power supplies to LANSCE capacitor rooms.[4]

The new LEDA HVPS systems will need to be modified to provide positive fail-safe control from racks located outside the capacitor rooms, 250 meters from the physical HVPS system. Emergency OFF buttons will be located on the T/R sets south of the road and at the four capacitor rooms at LANSCE. Pressing any Emergency OFF button shall open the main circuit breakers at the LEDA substation. The emergency OFF function shall be implemented such that it operates independently of computer control. It must also fail to a safe condition in the event of loss of control power either at the substation or in the klystron gallery.

Benefits of Maintaining the Existing LANSCE HVPS Systems as Backup Systems

The LEDA HVPS systems were designed to be ultra reliable, even when operated continuously at their maximum rated output voltage and current. This reliability was required for the APT accelerator design where over one hundred of the supplies would be simultaneously in use. Even though we expect the new HVPS systems to be much more reliable than the old HVPS systems, failures of the new systems are still possible. The failure of an oil-filled portion of an any HVPS system is typically a very long down time event. Usually specialized rigging and cranes need to be brought on site to remove the T/R subunit. The transformer then needs to be sent to a vendor for rework and repair. Weeks to months of downtime can result.

We intend to connect the LEDA HVPS systems to the first four sectors in a redundant configuration with the existing LANSCE HVPS systems. Nominal operation will be with the LEDA power supplies, but if a power supply should fail, we will be able to reconfigure to the existing sector supply within hours and continue to operate. The new high efficiency klystrons will be able to operate at the reduced voltage capability (90 kV) of the existing supplies at a reduced efficiency. Because the existing LANSCE klystrons are so low in efficiency, it is likely that we will still be able to support full beam operations if we lose a power supply from one of the 6-klystron sectors. If we need to reconfigure a power supply in a 7-klystron sector, we will likely be able to support the full peak beam current after reconfiguration but will probably need to reduce the duty factor by 10 – 20%. This approach should improve the overall reliability of the LANSCE HVPS systems and will also defer the disposal costs for the existing HVPS systems.

Challenges of Maintaining the Existing LANSCE HVPS Systems as Backup Systems

High voltage cables from both new and old HVPS systems will be brought into the capacitor rooms, but only one cable will be connected to the capacitor bank. The unused set will be terminated in a short rated for the maximum output current of the power supply feeding the cable. Engineered controls including captured-key interlock systems will be used to ensure the desired power supply configuration is maintained and to mitigate safety issues.

CONCLUSIONS

The LANSCE Refurbishment project will replace obsolete equipment that is nearing the end of its design lifetime. The replacement of this equipment can significantly increase the overall electrical efficiency of the AC to RF conversion systems. New, high efficiency klystrons require higher voltages than the existing LANSCE HVPS systems can provide. Completely replacing the existing LANSCE HVPS systems with similar or new technologies was found to be cost prohibitive. Therefore we devised a way to reuse existing 1990s LEDA HVPS systems that were installed at LANL as a part of the APT project. Leaving the new supplies installed in place 50 meters to the south and running the HV output cables under the road to LANSCE was found to be the most cost effective way of upgrading the accelerator. The annual electrical cost savings resulting from the upgrade of four sectors of klystrons and HVPS systems is estimated to be $650k (US$).

REFERENCES

[1] *Review of Condition Assessment of Power Transformers in Service,* IEEE Electrical Insulation Magazine, Vol: 18, Issue: 6, Nov-Dec 2002, pp. 12 – 25.

[2] *Diagnostic Techniques for Assessing Insulation Condition in Aged Transformer*, IEEE Transactions on Dielectrics and Electrical Insulation, Vol.10, No. 5, October 2003.

[3] IEEE, ‘‘IEEE Guide for the Interpretation of Gases Generated in Oil-immersed Transformers’’, IEEE Standard C57.104-1991, 1991.

[4] Satellite view of LANSCE, retrieved July, 2007 from website www.google.com.