Operation of Indus-2 with the support of high power Solid State RF Amplifiers

P R Hannurkar, Gurnam Singh, S K Shukla, A C Thakurta, T A Puntambekar, P Fatnani, S S Prabhu, C P Nawathe, Akhilesh Jain, M R Lad, Ramesh Kumar, M K Badapanda, Nitesh Tiwari and P D Gupta

RF System Division, Raja Ramanna Centre for Advanced Technology, Indore 452013

Abstract. Indus Accelerator complex at RRCAT houses two storage rings: Indus-1 and Indus-2. Booster synchrotron serves as common injector for these storage rings. Three major RF systems namely booster RF system, Indus-1 RF system and Indus-2 RF system have been developed and deployed for these accelerators. Booster and Indus-1 RF systems operating at 31.6 MHz are conventional Tetrode tube based systems. Indus-2 RF system was designed using Klystron tubes, operating at 505.8 MHz with maximum output power of 64 kW. During Indus-2 operation, some of the klystrons developed faults and only two klystrons which were bare minimum required for operating Indus-2 at 2 GeV, 100mA were available. As the availability of the klystrons from foreign sources was uncertain and existing two klystrons were in operation for a long period, it was decided to expedite the indigenous development of solid state high power amplifiers as replacement of Klystrons. It was also decided to deploy the solid state amplifiers in phased manner so that operational life of the existing klystrons may be extended and in case of failure of another klystron Indus-2 machine could be run at 2 GeV with the support of the solid state amplifiers. In the first phase, 15 kW solid state RF amplifier was developed and integrated with RF cavity No.1. With the support of this 15 kW Solid State RF amplifier, Indus-2 beam energy could be increased up to 2.2 GeV at 100mA. After successful operation of Indus-2 with the solid sate RF amplifier, another 15 kW RF amplifier was built and installed with RF cavity No.3.With addition of these two solid state amplifiers and optimization of RF system operating parameters, beam energy could be increased up to 2.3 GeV at 100mA. With the confidence gained in this development and the technological expertise generated in RFSD at RRCAT, development work to replace all four 505.8 MHz Klystron based RF power stations with solid state RF amplifiers has been taken up. The paper describes the development of solid state amplifiers as the critical import substitute system, their deployment for Indus-2 and operation of Indus2 with the support of solid state RF amplifiers.

Keywords: Solid State RF amplifier
PACS: 84.40.Dc

INTRODUCTION

In Indus-2 storage ring, 100 mA of beam current at 2 GeV has been stored successfully in March 2010 and since then Indus-2 is operating in round the clock shift operation [1]. Recently Tetrode Tube based booster RF Amplifier has been replaced by indigenously designed and developed 1kW solid state RF amplifier. This has resulted in improved performance of Booster synchrotron RF system. With the confidence gained in this development and the technological expertise available in

RFSD at RRCAT it was decided to replace the 505.8 MHz Klystron based RF power stations with solid state RF amplifiers (SSPA). Solid state amplifier offers many advantages like graceful degradation, low maintenance, high reliability, no warm up time and absence of high voltage points as compared to traditional tube based RF amplifiers. With rapid development in high power solid state RF devices, solid state RF power amplifiers have become viable solution for various particle accelerator applications [2]. After introducing Indus-2 RF system in brief, we shall present the development of high power solid state RF amplifiers and operation of Indus-2 with the support of solid state amplifiers.

Indus-2 RF System

Indus 2 is a synchrotron light source designed to operate at 2.5GeV/300mA. Booster synchrotron operating at 550MeV works as injector for Indus-2. Indus-2 RF system [3] comprises of four bell shaped RF cavities at 505.8 MHz, energized by four Klystron based RF amplifiers (Fig. 1.). High power RF source used in these amplifiers are multi-beam, integral cavity klystrons which gives more than 65 % of RF efficiency at full output power of 64kW with gain of 43 dB.

FIGURE 1. High power Klystron based RF amplifiers in Indus-2 SRS

Multi beam klystron results in lower cathode bias voltage requirement of 20 kV compared to single beam klystrons. Indigenously developed 10 watt solid state amplifier is used as driver for it. To protect the klystron from the reflected power from cavity under changing beam current in the ring a Y-junction 75 kW coaxial circulator is used. RF power from klystron to the cavity is transmitted through high power 6 1/8” coaxial line. Low Level RF (LLRF) control system plays a very crucial role in any Accelerator by providing phase and amplitude stable electromagnetic fields in the accelerating structure. LLRF systems for Indus-1 and Indus-2 synchrotron radiation sources are built using analog feedback techniques to control the amplitude and phase of accelerating field in the RF Cavities. LLRF system in Indus-2 also provides RF drive signal to each amplifier station and maintains the phase synchronism between all the four stations. For proper injection, acceleration and stacking of electron beam the phases of four stations has to be optimized and synchronized with the booster RF Signal. To accomplish this, 0 to 360 degrees controllable phase shifters in RF chain are used. Also any variation in the RF phase produced in the amplifier chain, circulator and transmission line is kept stable within

0.5 degrees of the set value. Operation at higher energies and higher beam current demands fast response of control loops for amplitude and phase.

Solid State RF Amplifier

For booster synchrotron a 1kW, 31.6 MHz MOSFET based high power Solid State RF amplifier has been developed, installed and commissioned with the Booster RF system. Output from four modules of more than 250 watt each is combined in two stages with Wilkinson type co-axial cable combiner. Required components like driver amplifier, MOSFET based 250 watt RF amplifier modules, high power co-axial combiner, low power splitter, harmonic filter, sampler and interlock unit were indigenously developed. This Solid State amplifier has replaced the existing Tetrode Tube based amplifier which had been running for past 10 years. The solid state amplifier system is working satisfactorily and has resulted in reduced downtime and maintenance.

Indus-2 RF power system at 505.8MHz was built using four Klystron based RF stations. Since these klystrons are imported and strategic items, difficulties are encountered to get their replacement. Today RF transistors, in the frequency range of few MHz to GHz and delivering continuous as well pulse power of the order of 300W to 1kW from single device, are available. Newer GaN technology is bridging the gap of higher frequency stability of GaAs and high power and voltage capability of silicon MOS devices. Also increasing use of solid state amplifiers is continually contributing towards improvement in performance and reduction in cost. In view of many advantages of solid state power amplifiers (SSPA) mentioned above, development of high power solid state RF amplifiers has been initiated as a replacement for klystron based amplifiers. The solid state RF amplifiers capable of delivering 20 kW and 30 kW RF power have been designed, developed and successfully integrated with RF cavities of Indus-2[4]. The scheme to build high power RF amplifiers involves development of 320 W basic RF amplifier modules employing MOSFET device BLF-573 and adding many such modules using appropriate combiners. We have developed four numbers of 8 kW RF amplifier units. Each 8 kW unit was housed in a single euro rack and employs 32 numbers of basic power modules which are combined using two co-axial line based 16-way RF power combiner and one 2-way combiner. Two such units were combined to achieve 15 kW. The RF power from two numbers of 15 kW RF amplifiers was again combined using two way high power combiner to get RF power of 30 kW. To get maximum combined output power, phase balancing of individual 8 kW units was done using variable phase shifters. This resulted in reduced reflected power at amplifier modules, increased overall efficiency and will also improve the long term performance of the solid state amplifier. In-house technology development of required RF components like high power amplifier modules, 2-way power dividers/combiners, 16-way power dividers/combiners, variable phase shifters, low and high power directional couplers, and RF dummy loads was carried out.

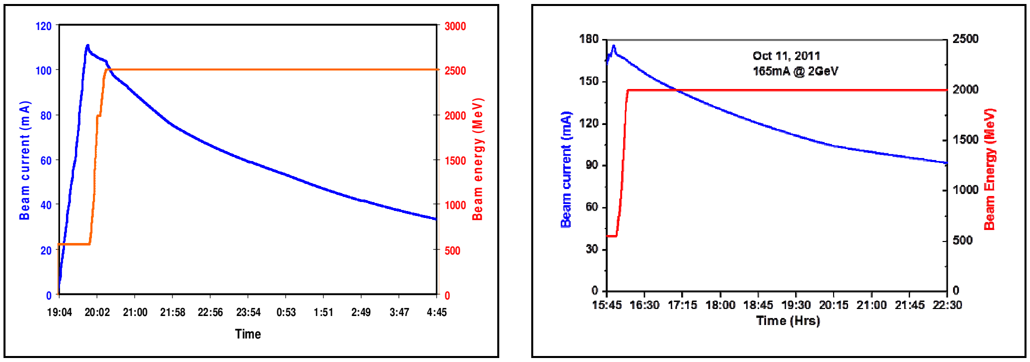
FIGURE 2: 30 kW high power amplifier

Indus-2 Operation

For installation of Solid State RF amplifiers in Indus-2 modifications were carried out in the existing RF system. This includes optimization of Low level RF feedback control system for amplitude and phase stability, frequency tuning system, and interlock system for protection. Also a new system was fabricated and installed for distribution of cooling water for solid state amplifiers.

Developed solid state amplifiers were installed in phased manner for Indus-2 operation. First a 15 kW solid state RF amplifier was installed with RF cavity No.1 and machine was operated with two klystron based amplifiers and one solid state based amplifier. As the maximum power available from the stations were different RF cavity gap voltages and RF phase of different stations were optimized to keep the solid state RF amplifier in linear region of operation. Also the feedback control loops for amplitude and phase were optimized so that RF cavity No.1 can be operated at lower RF cavity gap voltage. With the support of the solid state RF amplifier beam energy could be increased up to 2.2 GeV at 100mA stored current. This also increased the confidence and another 15 kW solid sate RF amplifier was installed with RF cavity No.3 and complete RF station was optimized for proper operation. With addition of this Solid State Amplifier and optimization of RF system operating parameters, beam energy could be increased up to 2.3 GeV for 100mA stored beam. By adding power from two 15 kW units with high power combiner, RF power of one station feeding power to RF cavity No.3 was increased to 30 kW (Fig. 2). Further improvement in the design of basic RF power module was carried out to increase the output power to 400 W. Using these modules power from RF amplifies unit was enhanced to 10 kW. Combining power from two such units' output power of 20 kW was obtained. With the support of these two 20kW and 30 kW newly installed solid state amplifiers, 103 mA of stored beam current at designed beam energy of 2.5 GeV was achieved. Remaining two stations were operated with klystron based amplifiers. The cavity gap voltage settings for this operation were 215 kV, 350 kV, 250 kV and 350 kV respectively for cavity No. 1 to 4. Indus-2 operation at increased beam current of 165 at 2.0 GeV was also carried out using these solid state amplifiers. Operation result at

2.5 GeV and 2 GeV are shown in Fig. 3 (a) and 3 (b) respectively.These solid state RF amplifiers have been operated in round the clock shift mode.



(a) (b)

FIGURE 3: Indus-2 operation (a) 2.5GeV, 100mA, (b) 2GeV, 165mA

Conclusion

Two of the four RF stations of Indus-2 are now running with solid state amplifiers having 20 kW and 30 kw of RF power capacity. With the support of these amplifiers, Indus-2 was operated at 103 mA at designed energy of 2.5 GeV. The experience gained will be useful for the development of high power solid state amplifiers for Spallation neutron source (SNS) and accelerator driven systems (ADS).

ACKNOWLEDGMENTS

We are thankful to large number of colleagues from RF systems division for their contribution for the development of high power solid state amplifiers. Many members of Indus operation team participated in deployment and operation of these amplifiers with Indus-2; it is our pleasure to thank them all.

REFERENCES

1. M Lad et al. “Commissioning & optimization of Indus-2 RF System for 2 GeV/100mA” Indian Particle Accelerator Conference, INPAC2011, India, (2011).
2. Elajjouri, M. “Status of the Soleil RF System.” 14th European Synchrotron Light Source Radio-Frequency Meeting. Trieste – Italy. (2010).
3. P. R. Hannurkar et al. “Design and commissioning of RF system for INDUS-2” Indian Particle Accelerator Conference, INPAC02, Indore, India, (2002).
4. P. R. Hannurkar et al. “Development of 505.8 MHz Solid State RF Amplifiers at RRCAT” 2nd International Workshop on Accelerator-Driven Sub-Critical Systems & Thorium Utilization Bhabha Atomic Research Center, Mumbai,India (2011).