Fusion Engineering and Design 115 (2017) 49–55

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Open loop control of filament heating power supply for large volume plasma device

R. Sugandhi[a,b,*], P.K. Srivastava[b], A.K. Sanyasi[b], Prabhakar Srivastav[a,b], L.M. Awasthi[a,b], S.K. Mattoo[b]

[a] *Institute for Plasma Research, Gandhinagar, Gujarat 382428, India*
[b] *Homi Bhabha National Institute, Mumbai 400094, India*

ARTICLE INFO

Article history:
Received 8 August 2016
Received in revised form
28 November 2016
Accepted 28 December 2016
Available online 11 January 2017

Keywords:
Process automation
Modbus
LabVIEW
Large volume plasma device

ABSTRACT

A power supply (20 V, 10 kA) for powering the filamentary cathode has been procured, interfaced and integrated with the centralized control system of Large Volume Plasma Device (LVPD). Software interface has been developed on the standard Modbus RTU communication protocol. It facilitates the dashboard for configuration, on line status monitoring, alarm management, data acquisition, synchronization and controls. It has been tested for stable operation of the power supply for the operational capabilities. The paper highlights the motivation, interface description, implementation and results obtained.

1. Introduction

Large Volume Plasma Device (LVPD) is dedicated to the laboratory investigations of phenomena governed by Electron Magneto Hydro Dynamics (EMHD) [1–4]. Various studies [1,2] carried out in this device are: excitation of nonlinear electron magneto hydrodynamic structures of the size of skin depth, formation of a large beta plasma and its characterization in terms of energy balance, diamagnetic response and excitation of bounded whistlers, lower hybrid, high beta electromagnetic turbulence excited by pressure gradients modified by energetic electrons [2] or the Electron Temperature Gradient (ETG) [5,6] and unambiguous observation of ETG turbulence etc. The plasma for these studies is produced by a filamentary source (14 kW), having its filaments ($n = 36, \quad \varphi = 0.5mm, \quad L = 18cm$) dispersed over the periphery of a rectangle of dimension (130 cm × 90 cm).

Main plasma parameters are 1) Plasma density ($n_e{\sim}10^{11}cm^{-3}$), 2) Electron temperature ($T_e{\sim}3 \quad eV$) and 3) Plasma beta ($\beta \geq 1$). For ETG studies, it becomes imperative to produce plasma devoid of energetic electrons of non-thermal nature. This could be done only when Electron Energy Filter (EEF) was embedded in LVPD plasma, which partitioned plasma into the source and target plasmas. Consequently, the plasma density ($n_e{\sim}10^{10}cm^{-3}$) is considerably reduced and so the plasma beta ($\beta{\sim}0.5$) in the target region. Further, the control on profiles of plasma parameters like plasma density and electron temperature was limited to a narrow range. More specifically, plasma beta in the source region ($\beta \geq 1$) reduced to $\beta < 1$ in the target plasma region suitable for ETG. The only way ETG studies can be carried out in wider range of plasma beta in target plasma is by increasing the plasma density in the source by an order of magnitude. This means higher discharge power and also higher emission current from the heated filaments. Hence, configuration of the source function in the source plasma has to be considerably modified. This can be done by dispersing filaments over the whole cross section covering the full diameter of LVPD. While bringing this modification, we also have to consider the experienced operational difficulties. Major difficulties stemmed from the use of thin filaments, used for electron emission. Use of thin filaments was dictated by the limited power capacity of the filament heating power supply. These thin filaments break quite often for different reasons related to formation of hot spots and $J \times B$ forces on the filament legs [7]. Another difficulty we ran into is the limited pulse width of the data, which could not be salvaged by improving the statistics of the data. Considering various configurations of filaments dispersed and their sizes ($n = 188, \quad \varphi = 1.6 \quad mm$ and $L = 18cm$) and compatibility with the use of 200 kW filament heating power supply, we adopted configuration of the filaments used for producing plasma discharges as shown in Fig. 1.

---

* Corresponding author at: Institute for Plasma Research, Gandhinagar, Gujarat 382428, India.
E-mail addresses: ritesh@ipr.res.in (R. Sugandhi), kushagra.lalit@gmail.com (L.M. Awasthi).

http://dx.doi.org/10.1016/j.fusengdes.2016.12.039
0920-3796/

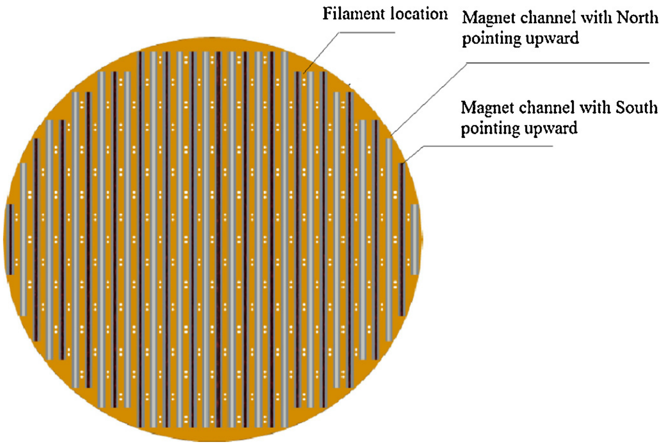

Fig. 1. Schematic showing the configuration for filaments in the new design of plasma source. The filaments are accommodated in the cusped plate having permanent magnets arranged in line-cusp geometry.

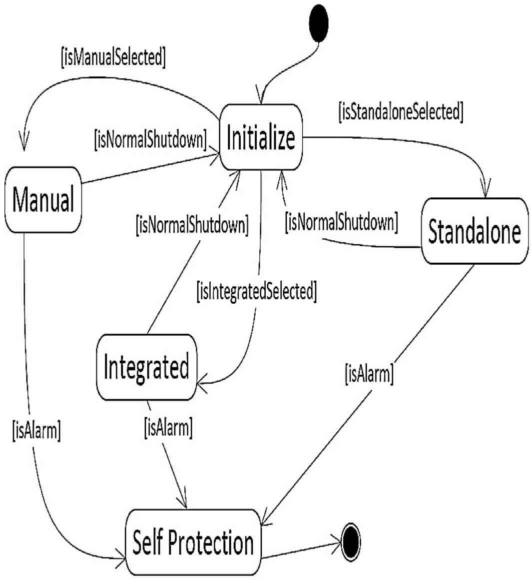

Fig. 2. Operation modes of the power supply.

A multi-function 200 kW Filament Power Supply (FPS) is procured to address the profile control and high plasma density in the target region of the plasma. The integrated operation of it with the LVPD system is the focus of this paper. Fig. 2 shows the operational modes of the power supply (PS). The power supply can be operated broadly in the following modes: (1) Initialize mode, which indicates availability of the required inputs for operation, (2) Manual mode, which indicates the operation from the manual knobs on the PS panel, (3) Integrated mode, which indicates the power supply is operated under the centralized control system of the LVPD, (4) Self-protection mode where the power supply goes in self-shutdown mode which is due to the internal failure of the power supply or any other alarm generated from external subsystems of the machine. The supplier has provided the manual and standalone mode of the power supply. The manual mode of operation is not useful when the power supply needs to be used for the long and frequent operational campaigns. In the standalone mode of the power supply, it is operated by a proprietary software executable, which emulates the front PS panel controls with no graph representation, data acquisition and fault diagnostics capabilities. Therefore, we have developed an integrated operational mode which is software driven and under the active control of the LVPD central control system. This mode is required to ensure the same clock timestamping, data acquisition and fault diagnostics support. The interface software developed follows the standardized communication scheme and development paradigm.

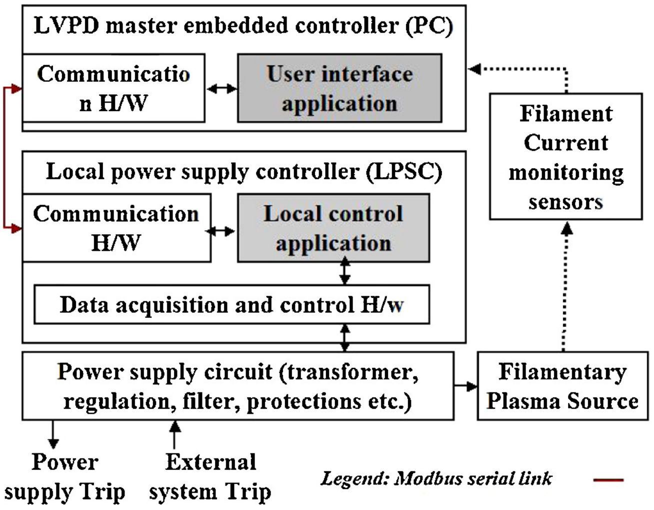

Fig. 3. FPS interfacing architecture showing open loop control (represented using solid line) and close loop control (represented using dotted lines).

The integration of the power supply is planned using two types of controls: (1) Open loop control and (2) closed loop control. The scheme of integration is shown in Fig. 3. Open loop control scheme is represented by solid line and closed loop control scheme is represented by dotted line. The open loop control scheme is implemented and reported in this paper. The architecture for integration in open loop controls has three tiers: (1) user interface application running on the master embedded controller inside centralized machine control application, (2) local control application running on the micro-controller based power supply controller board which interfaced with the power supply alarms, sensors and actuators for status monitoring and control command, and (3) standardized hardware and software communication protocol for interfacing. In the closed loop control, an additional block of current sensing electronics will be added for monitoring the current distribution in the filaments and accordingly handling the power supply set points. The change of the current distribution in filamentary cathode is due to malfunctioning or burning of a filament and may cause damage to the cathode. The implementations of closed loop controls are not in the scope of this paper and will be reported separately. Power supply provides hardware signal of trip for notification to other subsystems. It also has provision for trip itself when there is input on external system trip pin. One of its example is the accidental vacuum break condition in which filament breaks due to oxidation. A trip signal put the FPS into self-protection mode as shown in Fig. 2.

In the remainder of the paper, the filament power supply will be discussed in Section 2. The development and integration aspects will be discussed in Section 3. The results and conclusion will be discussed in Section 4 along with an overview of the future scope of the work.

The master embedded controller of the LVPD machine is an industrial controller (NI-PXIe 8135). It is running the application for filament power supply control and from now it will be referred as PC. The Local Power Supply Controller is referred as LPSC in the paper.

2. Power supply description and controls

The power supply hardware consists of the following subsystems namely, 1) Air circuit Breaker (ACB), 2) Two numbers of phase