The sun small resistivity enables it to absorb large amount of energy from weak magnetic fields.

The solar cycle is the mechanism by witch the galactic center transfer energy to the sun by magnetic fields.
The solar cycle across 22 years change the magnetic field polarity through the sun.
From Ulysses probe data shown graphically in Figure 25 the magnetic field at the peak of the solar cycle in year 2001 is about 4nT. This magnetic field is measured at a height of 1.4 AU from the sun surface. The distance 1.4AU in Meters is

$$R_{Ulysses} = 1.4 \cdot 1.49 \cdot 10^{11} = 2.1 \cdot 10^{11} \text{ M}$$

From Biot-Savart Law the magnetic field strength is inversely proportional to the distance squared so we can use it to find the strength of the magnetic field at the sun surface.

$$\frac{R_{Ulysses}{}^2}{R_{Sun}{}^2} = \frac{B_{Sun}}{B_{Ulysses}}$$

R_{Sun} The sun radius $6.96 \cdot 10^8$ M.
B_{Sun} The magnetic field at the sun surface.
$R_{Ulysses}$ The distance of the Ulysses probe from the sun when measuring the magnetic field.
$B_{Ulysses}$ The Magnetic fields measured by the Ulysses probe, 4nT from Figure 25.

So the magnetic field at the sun surface is:

$$B_{Sun} = \frac{R_{Ulysses}{}^2 \cdot B_{Ulysses}}{R_{Sun}{}^2} = \frac{(2.1 \cdot 10^{11})^2 \cdot 4 \cdot 10^{-9}}{(6.96 \cdot 10^8)^2} = 3.64 \cdot 10^{-4}\text{T}$$

Near iron magnet the magnetic field is about 100 mT, three hundred times then the above calculated value of the sun surface magnetic field.
In solar spots the magnetic fields can reach 1 T. So the above calculated value is reasonable.

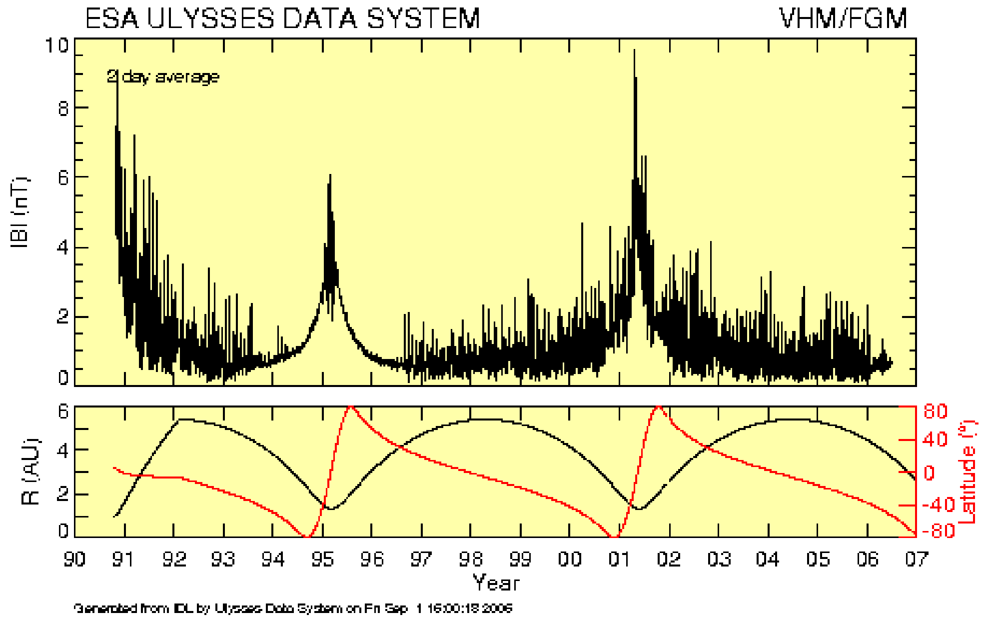

Figure 25: The magnetic field measured by the Ulysses probe near the sun. During 2001 when the sun was at solar maximum, and the probe was relatively close to the sun, the magnetic field measured was extremely high.

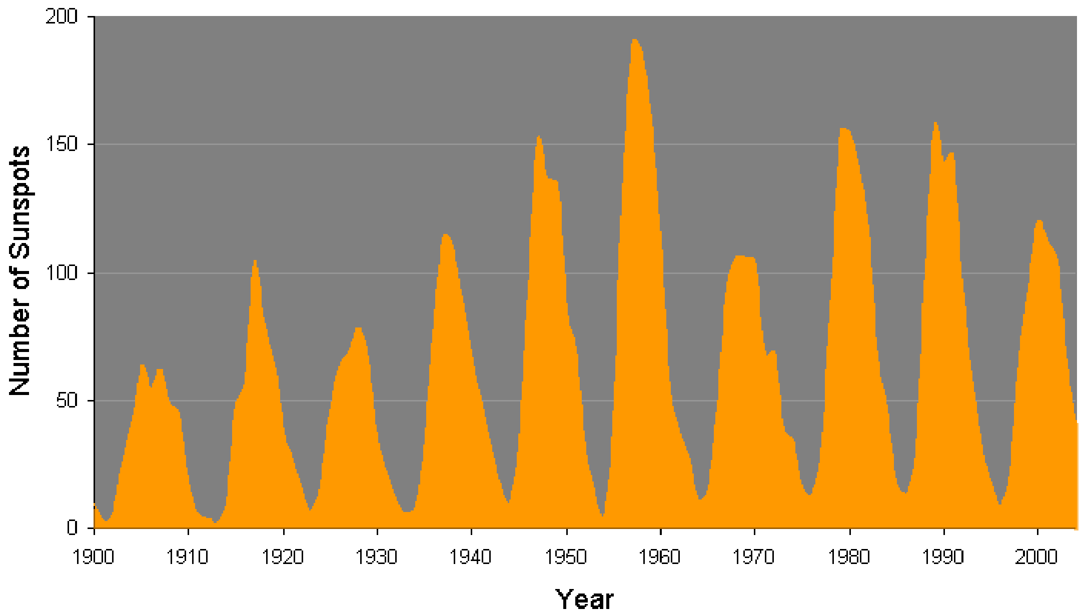

Figure 26: Century of solar cycles. During 2001 the number of sunspots indicates that the sun was at a solar maximum.

The sun was at solar maximum during the year 2001, as shown in Figure 26.
In 11 years the sun magnetic field will transform from the maximum in one polarity to the maximum in the reverse polarity. The maximum in one polarity is the calculated value above, therefore to get the change of the magnetic field during 11 years we need to multiple this value by two. To get the change of the magnetic field in one year we need to further divide by 11. From yearly value we can get the change of the magnetic field per second.

$$\Delta B_{Sun} = \frac{B_{Sun} \cdot 2}{11 \cdot 31536000} = \frac{3.64 \cdot 10^{-4} \cdot 2}{11 \cdot 31536000} = 2.09 \cdot 10^{-12}\,\mathrm{T} \cdot \mathrm{S}^{-1}$$

The magnetic field crosses the sun interior so we can use Faraday's Law to calculate the Electromotive Force (EMF). To get the magnetic flux that cross the sun we can multiply the magnetic field calculated above with the area of the sun. First we get the area of the sun.

$$A_{Sun} = R_{Sun}{}^2 \cdot \pi = (6.96 \cdot 10^8)^2 \cdot \pi = 1.52 \cdot 10^{18}\ \mathrm{M}^2$$

The electromotive force from Faraday's Law is:

$$E = \frac{\Delta \phi}{\Delta t} = \frac{\Delta B_{Sun}}{\Delta t} \cdot A_{Sun} = \frac{2.09 \cdot 10^{-12}}{1} \cdot 1.52 \cdot 10^{18} = 3.17 \cdot 10^6\ \mathrm{V}$$

The electromotive force is applied on the circumference of the sun. If we know the resistance of the sun we can calculate the energy or power dissipated by the currents inside the sun. To find the resistance we can imagine a donut shaped ring inside the sun enclosed by the sun circumference. This ring will have a circular cross section with radius that is, for instance, 0.3 of the sun radius. We can find the resistance of the donut shaped ring from its cross section area and from its length. The length of the ring is a circumference of a circle that its radius is smaller by 0.7 that of the sun radius.

$$l = 2\pi R = 2\pi \cdot (0.7 \cdot R_{Sun}) = 2\pi \cdot 0.7 \cdot 6.96 \cdot 10^8 = 3.06 \cdot 10^9\ \mathrm{M}$$

The cross section area of the donut shaped ring.

$$A_{Ring} = R^2 \pi = (0.3 \cdot R_{Sun})^2 \cdot \pi = (0.3 \cdot 6.96 \cdot 10^8)^2 \cdot \pi = 1.36 \cdot 10^{17}\ \mathrm{M}^2$$

To find the conductivity of the sun we can use the formula:

$$\sigma = 0.003 \cdot T^{3/2}$$

That is found in: “The Sun: An Introduction” by Michael Stix. 1989 page 308. Setting a temperature of 4000000 K that is found in the Sun upper ratiative zone gives:

$$\sigma = 0.003 \cdot T^{3/2} = 0.003 \cdot 4000000^{3/2} = 2.4 \cdot 10^{7} \ \mathrm{S \cdot m^{-1}}$$

And the resistivity is:

$$\rho = \frac{1}{\sigma} = \frac{1}{2.4 \cdot 10^{7}} = 4.17 \cdot 10^{-8} \ \Omega \cdot \mathrm{m}$$

Now we can find the resistance of the donut shaped ring.

$$R_{Ring} = \rho \cdot \frac{l_{Ring}}{A_{Ring}} = 4.17 \cdot 10^{-8} \cdot \frac{3.06 \cdot 10^{9}}{1.36 \cdot 10^{17}} = 9.38 \cdot 10^{-16} \Omega$$

The power can be found by the electromotive force and the resistance.

$$P = \frac{V^2}{R} = \frac{(3.17 \cdot 10^{6})^2}{9.38 \cdot 10^{-16}} = 1.07 \cdot 10^{28} \ \mathrm{W}$$

The radiation emitted or luminosity of the sun is $3.86 \cdot 10^{26} \ \mathrm{W}$.
The mass lose rate from mainly from solar wind is $10^{9} \ \mathrm{Kg \cdot S^{-1}}$. The energy equivalent of this mass is:

$$E = MC^2 = 10^{9} \cdot (3 \cdot 10^{8})^2 = 9 \cdot 10^{25} \ \mathrm{W}.$$

The energy supplied to the sun by the magnetic fields associated with the solar cycle is higher then the radiation emitted by the sun and the energy equivalent of the mass loss of the sun.

It is also possible to show that the strength of the magnetic field needed to sustain the energy consumed by the sun is smaller then the magnetic field measured by the Ulysses probe. If we neglect the energy required to produce new mass in the sun, then the energy consumed by the sun is equal to the sum of the radiation emitted and the solar wind mass loss.

$$E_{Total} = 3.86 \cdot 10^{26} + 9 \cdot 10^{25} = 4.76 \cdot 10^{26} \ \mathrm{W}$$

Form this energy consumption and the resistance of the sun, we can find the electromotive force.

$$V = \sqrt{P \cdot R} = \sqrt{4.76 \cdot 10^{26} \cdot 9.38 \cdot 10^{-16}} = 6.68 \cdot 10^{5} \text{ V}$$

From Faraday's law we can find the magnetic field at the sun surface.

$$\Delta B_{Sun} = \frac{E \cdot \Delta t}{A_{Sun}} = \frac{6.68 \cdot 10^{5} \cdot 1}{1.52 \cdot 10^{18}} = 4.39 \cdot 10^{-13} \text{ T} \cdot \text{S}^{-1}$$

To find the magnetic field change during one year we can multiple the magnetic field change per second with the number of seconds in a year.

$$\Delta B_{Sun} = 4.39 \cdot 10^{-13} \cdot 31536000 = 1.384 \cdot 10^{-5} \text{ T/Year}$$

The magnetic field strength is inversely proportional to the distance squared so at altitude of 1.4 AU the magnetic field will be.

$$\Delta B_{Ulysses} = \frac{\Delta B_{Sun} \cdot R_{Sun}{}^{2}}{R_{Ulysses}{}^{2}} = \frac{1.384 \cdot 10^{-5} \cdot (6.96 \cdot 10^{8})^{2}}{(2.1 \cdot 10^{11})^{2}} = 1.52 \cdot 10^{-10} \text{ T/Year}$$

This value is smaller then the values typically measured by the Ulysses probe so even though the magnetic fields are considered small they sufficiently supply the energy consumption of the sun.