Concept Design And Feasibility Study of a Grid Free Solar Power Source for Small Scale Industries in Remote Areas Using Flywheel Batteries

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***Abstract*— this paper presents a concept design of grid free solar power source. This design aims at creating a power source which can be utilized as a regular power source by remote rural industries. This paper attempts to present economically viable solution. The design proposed here is expected to be simple and will utilize technology which is appropriate for rural areas and rugged. The steady fall in the price of solar panels over the last decade has made it possible to adopt this as an alternative to paying extra cost of laying electric lines for use in remote areas. The use of flywheel batteries will drastically reduce the recurring cost of replacing chemical batteries. The technical feasibility of the proposed power source has been established by various applications of flywheel batteries and standby power sources already in use on commercial basis. An economically feasible solution utilizing appropriate technology for rural areas is urgently needed in India. The use of flywheel batteries will enable this. This design proposes to use the power source only during daytime which will eliminate the need of expensive energy storage arrangements for the night hours. The mechanical characteristics of this source are expected to be similar to the 5 Hp Genset since this design proposes to use a flywheel which is even larger than the one used on these Gensets. A prototype of the solar power source is being fabricated in the laboratory. It will be tested for its performance on actual loads. The paper gives detailed discussion about the use of a flywheel battery for grid free solution. It appears that this is one of the best solutions for the present state of the technology appropriate for rural areas. In the near future the use of flywheel batteries will increase and replace the chemical ones. The flywheel batteries will not only be used for providing backup power for critical power requirements (which is a regular practice at present) but also for creating motive power source.**

I. INTRODUCTION

This paper presents a concept design for grid free solar power source. This concept design aims at creating a power source which can be utilized as a regular power source by remote rural industries. The main difficulties of using the solar power are

The recurring cost of the chemical batteries.

The starting surge currents in electric motors

The flywheel batteries are getting popular but are expensive

This paper attempts to present economically viable solution. The design proposed here is expected to be simple and will utilize technology which is rugged and appropriate for rural areas. The small industries in remote areas are mostly service industries. These industries use motive power for running small electric motors. The grid free source of electric energy using solar Photo -Voltaic panels should become a cost effective proposition in the near future. The steady fall in the price of solar panels over the last decade has made it possible to adopt this as an alternative to paying extra cost of laying electric lines. The use of flywheel batteries will drastically reduce the recurring cost of replacing chemical batteries. The flywheel batteries have an inherent capacity to tackle large current surges. The flywheel stores large amount of kinetic energy and it can be supplied instantaneously. The cost of the flywheel batteries can be considerably reduced with simple designs and by adopting suitable size of flywheel. The battery requirement of a typical rural industry is only for absorption of current surges and getting a steady supply. The currently available flywheel batteries are designed to provide backup for critical power. The concept design presented here is only for absorbing the starting

surges and for giving steady power supply. The concept design presented here is based on the flywheel storage capacity sufficient for the specific purpose mentioned above. There is an urgent need of such an economical design which can be adopted by the industry as an alternative to the expensive electric lines for which industries are required to pay for. At the same time this will permanently free them from the liability of paying electric bills. More over it is a green solution, only with one great disadvantage i.e. power will be available only in daytime. It is hoped that this simple design will be useful from these considerations, or at least it will pave the way for the development of better design.

II. NEED OF GRID FREE POWER SOURCE

The present work proposes to design a power source for the rural industries. The rural electrification program has inbuilt lacunas. Many villages in remote areas, which are electrified as per records, hardly have electric supply. Even in an electrified village the availability of electric supply to a point say 500 meters away from the electric lines will cost around Rs. 100,000/- over and above the normal connection charges. The electric bill will be a recurring expenditure for the consumer. In some cases if H.T. transformers of adequate capacity are not available in the vicinity then the consumer may have to cough up even more money for the transformer cost as well

In short the expenses for getting a connection for 1-5 KW at just 500m (7-8 Poles which is quite common in rural areas) from existing lines may be anywhere between Rs.150000 to 200000. Apart from this there may be risk of facing load shedding during daytime (peak hours).

This is not a problem relevant only to Indian conditions even in developed countries new remotely located housing colonies/settlements have to pay in millions (for extension of electric lines/ grid). There are many reported cases where the residents have decided to have grid free power source instead. These power sources are based on combined solar and wind energy and normally above 1 MW. Many such alternative sources are successfully operating for years. Apart from economic considerations there are environmental issues which make these units even more relevant. This may even entitle them for carbon credits.

In the Indian context there is urgent need of such a grid free power source. The rural electrification program is incapable of giving 24 hours of power supply and especially during working hours of the day which is the peak time of the grid. This grid free industrial solution may also help in generating employment in the rural area. The flight of the rural workforce to the cities is another important social issue.

An economically feasible solution utilizing appropriate technology for rural areas is urgently needed in India. The use of flywheel batteries will make this possible. This design proposes to use the power source only during daytime which will eliminate the need of expensive energy storage arrangement for the night hours.

III. DEFINITION OF THE PROBLEM

Here an attempt is made to define the problem of designing the grid free power source based on commercially available elements and which can be locally fabricated in the rural areas. The relevant data about the proposed solar power source can be summarized as

- The power source is to be designed for 1500 watts to 3750 watts (2 - 5 Bhp)
- Assuming the losses in the system, the main P.V. panels will be of 25% more capacity i.e. 1875 watts to 4800 watts
- The supply from photo voltaic (PV) panels will give D.C. in the Voltage range of 48V to 196 volts or any other voltage may be adopted with and suitable series / parallel connections.
- The output from the source should be either A/C 230 V single phase 50 hertz or A/C 410 V Three phase 50 hertz.
- The expected frequency could be in the range 48 to 52 hertz.
- The power source will be available from sunrise to sunset only.
- The flywheel battery will store energy up to 75-300KW-Sec (approx. 100-400 HP sec.) energy.

The above data forms the basis for the designing the Solar Power Source. The requirements have to be framed on this basis and a suitable problem definition has to be evolved. A brief definition of the design problem could be

Design a power source to feed a load of 2000 watts (It may be inclusive). The available power source is solar power from PV Panels with an energy storage capacity of around 75-300KW-Sec; the flywheel battery should have a back up capacity of around 75-300KW-Sec. The flywheel battery will not be able to give a sustained backup but only for absorbing the load surges.

IV. ENGINEERING DESIGN CONSIDERATIONS

The main elements of the proposed solar power system will have the following essential elements apart from the supporting parts (Assuming a design for 2000 Watt A/C power source)

- PV Panel of at least 25% extra generation capacity, say 2500 watts.
- A flywheel capable of storing around 100 to 400 Hp second of Kinetic energy
- A suitable shaft frame bearings etc to rotate the flywheel at synchronous speed of 1500 RPM.
- An Alternator / Dynamo (DC Generator) of around 3000 watts capacity.
- An electric motor A/C230 V 1 Ø AC induction with 2500 watt or DC motor of the same capacity.

- Suitable electronic equipment to convert AC to DC or DC to AC depending on the selection of Alternator and motor.
- Requisite steel frame to accommodate these things and connect them.
- A suitable panel to note the relevant voltage, current, frequency, RPM and other major parameters of the system.
- An arrangement to energize the flywheel to operating speed.

All these elements when properly arranged may be called as a grid free solar power source. The grid free power sources that are in use, are mostly designed for a 24 hour power supply which requires a back up of 12 hour which is mostly met by chemicals batteries or gensets etc. whereas the present design proposes to use the power source only during day time when the sunlight is available. The industries work on an 8/12 hour shifts can easily use this power source. The typical example which was in the news is of the diamond polishing industry which required small motive power for their operations and frequent power cuts/or load shedding made it very difficult for the industry to survive . Such and similar industries may be operated in even the remote jungles with no grid around.

The idea of using power only during sunshine decreases the power storage requirement. The low storage and high power density character makes flywheel Batteries most suited for such applications. Roughly the power flow diagram for the power source will be as given in Fig. 1

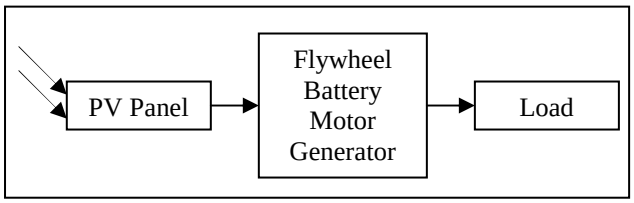

Fig. 1. FLOW OF POWER THROUGH THE GRID FREE SOLAR POWER SOURCE

V. POWER ELECTRONICS

The main part of any power source will be the power electronics involved in the whole set up. This design aims at a power source for the rural area hence it is proposed to use standard types of power electronics in the design. The commercially available power electronics utilities are inexpensive and easy to maintain. This feature is mainly due to the mass scale production of these products.

The power electronics applications which are custom built are not only expensive but are difficult to maintain. The main power electronics requirement of this design would be inverters and rectifiers in certain special designs.

A. The static inverters

These are devices which convert DC in to 50 hertz AC. The frequent power failures and load shedding in almost all parts of the rural India has made it a very popular product. It is estimated that at least 10 million static inverters are in use in India. The commercially available inverters are normally rated for 800, 1500, 3000 watts. Small numbers of inverters with higher ratings are also available. These inverters work mainly as a backup for the domestic lighting and fan connections. These inverters are using the lead acid batteries as storage device. These inverters can even be used for running refrigerators and other small power devices. Such inverters have higher power ratings and larger batteries.

The main purpose of giving the details of these inverters is to emphasize the proliferation of this inverter technology in the rural areas. This design being one aimed at utilizing appropriate technology proposes to use only the inverters which are easily available in the market at reasonable prices. There is no intention to design any power electronics part especially for this purpose.

B. The Grid Tie Inverters

This is a special type of inverter at present not so popular in India but the advent of the solar inverters will make it feasible in future. In some countries the local law allows the electric consumers to install these types of inverters. These types of inverters are used along with renewable power sources such as solar wind etc. The inverter allows the electricity generated by the solar panels to be synchronized with the mains/grid. The consumer uses the energy generated by the solar panels for his applications and the excess power may be fed in to the grid. The consumers are billed accordingly.

In India also the major producers of renewable energy feed the generated electricity in to the grid with these grid tie inverters. The grid tie inverters remain tied to the grid frequency and are always synchronized with the grid hence they are so named. The present design may be modified with the help of such inverters to improve the efficiency in future.

VI. GENERATION OF ALTERNATIVE SOLUTIONS

The type of solutions of this design problem may be categorized in three types.

A. Based on the generator coupled to the flywheel

Flywheel will mainly work as the power booster element to absorb the power surges in operating conditions. There may be two types

1) An alternator (AC generator) coupled to the flywheel battery see Fig. 2

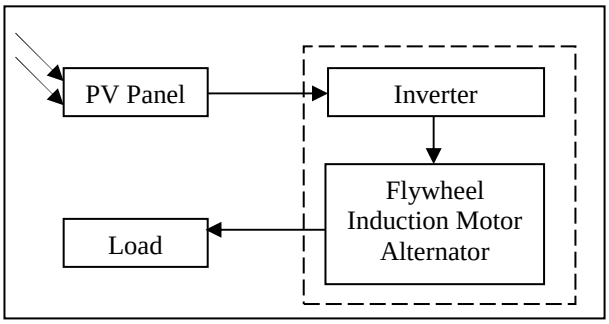

Fig. 2. FLYWHEEL BATTERY GENERATES A.C.

2) A DC generator (dynamo) is coupled to the flywheel Battery see Fig. 3

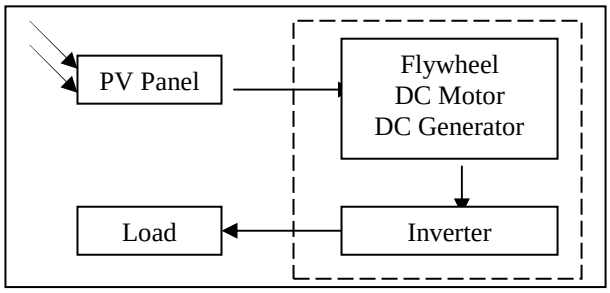

Fig. 3. FLYWHEEL BATTERY GENERATES D.C.

B. Based on the power used for energizing the flywheel (i.e. type of flywheel motor)

1) An induction motor is used (AC motor)

2) A DC motor is used

C. Based on the use of grid tie inverter or a DC feed forward for enhancing the overall efficiency. See Fig. 4

1) Using grid tie inverter for type A1.

2) Partly using DC power for running flywheel motor.

The third category of power source may be based on the continuous supply of energy to the load directly from the PV panels. This supply will have to be synchronized with the flywheel battery power with a grid tie inverter.

D. DESCRIPTION OF SOLUTION 1

The Power source is to be designed for running industrial loads which is mainly Induction motors 1Ø or 3Ø. These motors are generally connected to some more parts having inertia. The starting current of such loads is normally 5-6 times the normal running current when started with Direct online starters.(DOL) The DOL starter are commonly used with small motors up to 5 HP

An alternator of 5-10 HP capacity coupled to a flywheel can easily be used to start small size motors with DOL starters. The alternator has momentary current over load capacity (5-6 times). At the same time the flywheel has enough stored energy to support this momentary surge in current and power demand by the load.

There can be two alternatives here the entire DC power generated by the panels may be supplied to the flywheel motor. Thus the load is supported by the alternator and as shown in Fig. 3

Alternatively an inverter may be used to convert the solar DC power to A/C and augment the alternator power of the flywheel battery with it. This is shown in Fig. 4

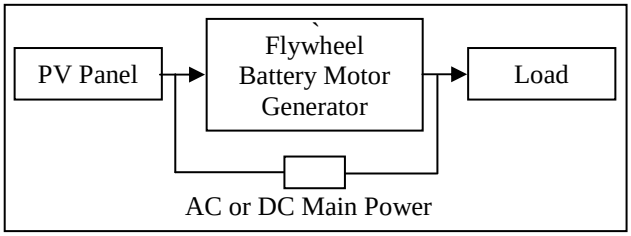

Fig. 4. LOAD IS CONNECTED TO FLYWHEEL BATTERY AND DIRECT POWER FROM THE PHOTO VOLTAIC PANELS

E. DESCRIPTION OF SOLUTION 2

This power source is having a dynamo or generator coupled to the flywheel. So the flywheel kinetic energy will be available at the load point through an inverter. This is shown in Fig. 3

In this case the load current of induction motors when started by DOL starters will require 5-6 times normal running current to be supplied momentarily. The inverter will have to be designed to take large overload currents and as we know electronic equipments /components are designed for precise current capacities. In short the inverter will have to be of a higher rating say 5-6 times.

In this combinations also the flywheel motor may be supplied part of the energy generated by PV panels and the rest can be directly given to augment the DC generator run by flywheel battery. See Fig. 4

Alternatively all the energy from DC of Panels may be given to the flywheel motor and the output of the DC generator will be connected to the load through the inverter.

The two designs discussed earlier may have the output either through an alternator or an inverter getting supply from the DC source created by flywheel dynamo.

In short there could be eight combinations

- A1 B1 C1
- A1 B1 C2
- A1 B2 C1
- A1 B2 C2
- A2 B1 C1
- A2 B1 C2
- A2 B2 C1
- A2 B2 C2

VII. EVALUATION OF THE ALTERNATIVE

Although so many solutions are available for simplicity only two are selected for the process of evaluation. The feed forward arrangement described in C2 type solutions is currently ignored for simplicity it will be useful in future designs only for improvement of the overall efficiency of the system designs .The solution given as A2 is also ignored for the present situation since this will require a much larger size it inverter and make the whole system expensive. In short only the A1B1C1 and A2B1C1 solutions are evaluated here.

A. SOLUTION A1 B1 C1

1) Merits:

a) It is simple in construction.

b) The inverter of adequate capacity matching the PV Panel capacity may be used with appropriate over load capacity.

c) There will be no necessity of synchronization.

d) The flywheel motor will be easily available and inexpensive.

e) The alternator of required capacity may be selected this being a standard product in the market will also be inexpensive.

f) This will be a rugged arrangement for handling the inductive loads of a small industry.

2) Demerits

a) The induction motor and alternator speeds will be different requiring a 4% increase in the frequency of the inverter.

b) Starting the flywheel i.e. Initially will require some arrangement.

c) Three step energy losses will be there (1) at inverter (2) at induction Motor (3) Alternator.

B. SOLUTION A2 – B1 – C1

1) Merit:

a) This solution will have the advantage of higher overall efficiency.

b) This is suitable for use in grid connected application.

2) Demerits:

a) This solution has the main drawback of the load being fed by an electronic device which will require much higher current and power capacities for the inverter.

b) The inverter will be expensive.

c) This requires DC machines to be used which are not easily available and are uncommon.

d) All DC machines are difficult to maintain.

VIII. SELECTION OF GRID FREE POWER SOURCE COMPONENTS

The solution 1 is selected for its simplicity, ruggedness and ease of use in rural industries. It may have less efficiency but overall economy and other reason mainly that of the choice of appropriate technology is accepted and the same is being fabricated for testing. Electronic solutions tend to become economical in long run due to design improvements and mass scale manufacturing. The future of this type of a grid free power sources may utilize electronic inverters but that phase of technological innovation may become relevant after a few years.

At present the best solution is only one that is selected. Fig. 5 gives the schematic arrangement of the design. Fig. 6 gives the block diagram of the same

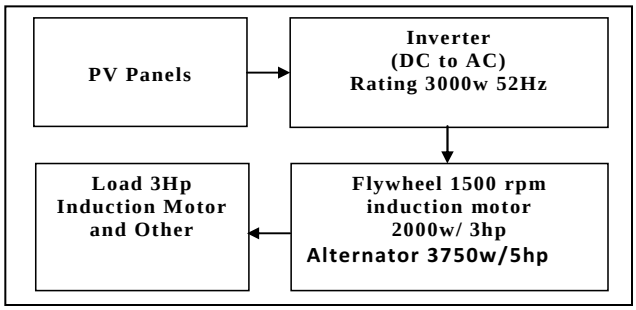

Fig. 6. BLOCK DIAGRAM OF THE DESIGNED GRID FREE POWER SOURCE

The inverter frequency may be adjusted to 52 Hertz. This will compensate for the speed of the induction motor which is around 4% lesser than the synchronous speed of the motor. The commercially available inverters have this facility.

The flywheel- motor –Alternator assembly may be initially rotated before starting using some auxiliary source/ arrangement. The inverter may not be able to absorb the large starting current of the assembly.

The mechanical characteristics of this source are expected to be similar to the 5 Hp genset.

A mathematical model based on the mechanics of the system and the characteristics of motor and alternator is developed to analyze and predict the performance of this power source. A prototype of the solar power source is being fabricated in the laboratory. It will be tested for its performance on actual loads and also to validate the proposed mathematical model.

IX. CONSLUSION

The Detailed discussion about the use of a flywheel battery for grid free solution appears to be the best for the present state of the technology appropriate for rural areas. But the development in the field of power electronics will definitely change state of the technology. Totally new or improved designs may come up in the future but the need

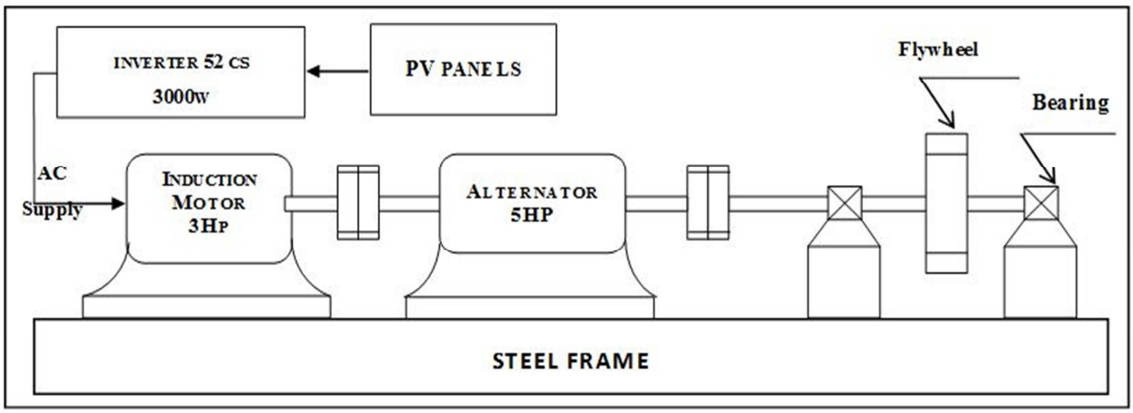

Fig. 5. SCHEMATOC DIAGRAM OF THE DESIGNED GRID FREE

for such designs will not diminish. It will take new forms but the chemical batteries will become obsolete in the future that is certain. The flywheel batteries will not only be used for providing backup power for critical power requirements but also for creating motive power source.

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