Delivery of Single Phase Power for Remote areas through Three Phase Self Excited Induction Generator by Series Shunt Capacitor Excitation Scheme

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Abstract:- Electric power has significant role and of vital importance in the development process of a country. By using appropriate capacitor bank connected across the terminals the induction machines could be used as Self Excited Induction Generator (SEIG) to cater the demands of remote areas, utilizing the locally available non-conventional energy resources. For large single phase power requirement in hilly or remote areas it became necessary to use single phase extension instead of three phase extension for economics point of view. In that case single phase power could be supplied through three phase SEIG. In order to get single phase power from three phase SEIG, Series Shunt Capacitor Excitation Scheme could be used. Under this scheme balanced operation could be obtained over the 84% range of load.

Index Terms: Cost Reduction, Exciting Capacitor, Self Excited Induction Generator, Single Phase Load.

1. INTRODUCTION

Electric power has significant role and of vital importance in the development process of a country. The grid power has often become inadequate or not available to remotely located and rural areas. Traditionally diesel fed synchronous generators are used for remote area power supply. The excessive use of the conventional sources of the energy has increased the fast depletion of the fuel reserves. This has resulted in the subsequent increase in energy cost, the environmental pollution and above all the global warming. Many studies have been conducted to rationalize the use of the conventional sources of the energy and to explore the use of other forms of the energy. This has motivated the world wide interest in reducing the pollution and conservation of the limited conventional fuels by encouraging more and more use of the energy available from the nonconventional/ renewable sources such as wind, the biogas, the tidal waves and the small hydro power stations built on the running canals and rivulets. The potential of the energy available from the small hydro and the wind sources, seems to be quite promising to meet the future energy demands, specially in the remote and the isolated areas. The electric power generation from these sources will not only supply the energy to the remote and isolated areas, but can also supplement the power requirements of the interconnected systems. The squirrel cage induction generators are receiving much attention for such applications due to its low cost and robust construction. Their overall operational and maintenance simplicity makes them being favoured for this type of applications.

An induction generator is ideally suited for use in small and medium power plants to harness the locally available resources in order to feed the power to isolated areas or the areas connected to common grid. The induction generator can be driven by the hydro turbines like the water wheels or small hydro turbines operated by the velocity heads in the rivers and canals, the ultra low heads on the canal falls, small hydro heads on the streams in the hills and the heads created by the tidal waves. An induction generator can be used as an isolated source of supply and may be used as a stand-by supply in the hospitals, the libraries, cinema halls, auditoriums, telephone exchanges, railway booking and signaling, computers, office complexes and the guest houses.

The squirrel cage induction generators have been preferred in comparison to the synchronous generators for small scale power generation due to their low cost, robust construction and ease of maintenance. The induction generators do not require a separate dc exciter and its related equipments like field breaker and automatic voltage regulator. Therefore such generators need minimal maintenance. The protection of the machine is simple and cheap because the fault current level of the machine collapse to zero as the capacitor excitation falls with terminal voltage. In case of the short circuit across the machine terminals, the sustained transients are not generated due to the absence of field.

The mathematical tools for analysis of the SEIG were made available in early eighties. The effectiveness of these tools have led to growing research on the SEIG during last decade. The steady state analysis of the SEIG has been essential for performance prediction, effect of system parameters, and design of the SEIG.

2. REVIEW OF LITERATURE

The possibility of operating induction machine as self excited induction generator was demonstrated in the decade of nineteen thirties [1]-[3]. The phenomenon of self
obtained at any desired value of slip. The interests of research on the induction generator were accelerated after oil crisis of seventies when the need of exploiting the renewable energy resources as an alternative to fossil fuel were realized by many countries. Wind, hydro, tidal, solar and bio-mass have been identified as possible sources of renewable energy. The prediction of performance characteristics of the three phase SEIG under no load and loaded conditions has been given by [13].

Reference [6] gave a simple method for computing the minimum value of capacitance required for initiating voltage build-up in three phase SEIG. Based on the steady state equivalent circuit model, a consideration of the circuit conductances yields a 6th degree polynomial in the per unit frequency. The polynomial can be solved for real roots, which enables the value of minimum value of capacitance. Reference [10] presented a simple new approach for computing the minimum value of capacitance necessary to initiate the self excitation process in three phase isolated induction generators.

In low power range of renewable energy application, single phase power generation is preferred to make the scheme cost effective. However, the use of single-phase induction machine of integral kW ratings are uneconomical as compared to equivalent size three phase induction machine. So the use of a three phase induction generator for single phase power generation is needed. Analysis of three phase machine connected to single phase ac mains is well known in motoring mode [12]. Operation of the three-phase grid connected induction generator in a single phase power system is reported in reference [9], [11]. Following this work, [5] have proposed an unbalanced excitation scheme, named C-2C configuration, and have concluded that it offers balance operation of three-phase delta connected SEIG feeding single-phase load at partial power output. However, the scheme was suitable only for constant power application. A scheme of three-phase induction generator, self excited by a single excitation capacitor across any two stator terminals and supplying a single phase load connected across it, was reported by [14]. Reference [8] analysed the performance of a three phase induction generator which was connected to a single phase power system. He showed that significant improvement in machine performance can be obtained by using a single static phase converter, provided that the machine was driven in the reverse direction. If two phase converters are employed, perfect phase balance can be obtained at any desired value of slip.

2.1 Single Phase Supply Through Three Phase SEIG

Need of operating three phase SEIG for single phase load arises in the situation when large rating generator is required to power single phase loads. Three phase machines are often used for single phase power generation for the capacity more than 5 kW because the single-phase induction machines are not widely available in integral kW ratings, have lesser efficiency and higher cost than the equivalent sized three-phase induction machines. Need of operating three-phase SEIG for supplying single-phase load arises in the following situations:

i. when the cost of bringing three-phase power to the location is high because of the construction costs of the required length of three phase extension,
ii. when large rated SEIG is needed to power single-phase loads,
iii. when the single-phase SEIG has higher cost than the equivalent sized three phase SEIG.

The single phase power generation using three phase SEIG is achieved by balanced operation of the three phase SEIG by variation of combined reactance of load compensation elements and excitation capacitances with load. But in this scheme a continuous variation of capacitances required which is a little difficult task. To overcome this difficulty Series Shunt Capacitor Excitation Scheme could be used which gives the balanced operation in the 84% range of load.

So, where the need arises the power may be given to the far located remote areas by three phase SEIG as single phase load making proper study of the load profile of that area.

3. Material and Methods

3.1 Balanced Operation Scheme

A single phase load is converted to balanced three-phase load by load compensation. The load compensation involves two steps: (a) load balancing and (b) power factor correction. The excitation capacitance required for exciting the SEIG at no-load when combined with the elements of load compensation gives a resultant terms which may be inductive or capacitive depending upon the load.

3.2 Partial Balanced Scheme

The susceptance to be connected across the three phases for balanced operation of the scheme are to be varied continuously with load. The necessity of varying the capacitor and inductor for the balanced operation increases the cost of the SEIG system. Therefore perfect balancing is not economical, a partial balancing scheme may be used as a compromise by removing the inductive reactance portion of the excitation balancing network and fixing the capacitance at a value. But, a fixed value of the unbalanced excitation elements gives rise the unbalance voltages. Since the induction machines are very sensitive to voltage unbalance, the severe current unbalance even for moderate values of voltage unbalance increases the total copper loss. As a result, the machine must be derated.

In the present work, a new excitation configuration containing of two capacitors, one across a phase and other in series of load, is proposed. This scheme is termed as Shunt and Series Excitation Scheme. This paper presents the investigation on the steady state analysis of Shunt and Series Capacitor Excitation schemes. The analysis of these schemes
will be performed based on positive and negative sequence components caused by unbalanced condition. Shunt and Series Capacitance Excitation Scheme.

Fig. (1a) shows a circuit diagram of three phase SEIG having connected a shunt capacitor $C_{bsh}$ across line b-c and feeding a single phase load through a series capacitor $Z_{se}$.

The terminal constraints of this circuit are:

1. $V_{sa} + V_{sb} + V_{sc} = 0$  
2. $V_l = V_{sa} - I_l Z_{se}$  
3. $I_l + I_a - I_c = 0$  
4. $I_{bsh} + I_b - I_c = 0$  
5. $V_{sb} = Y_{bsh} I_{bsh}$

where,  
$Y_{bsh} = j\Omega C_{bsh}$

Using symmetrical component concept we can get

1. $V_0 = (V_{sa} + V_{sb} + V_{sc})/3 = 0$  
2. $V_l = V_{sa} - I_a Z_{se}$

substituting symmetrical components for the phase voltage and currents, we get

1. $V_l = K_1 V_+ + K_2 V_-$  
where
$K_1 = 1 + (1-a) Y_+ Z_{se}$
and
$K_2 = 1 + (1-a_2) Y_- Z_{se}$

Eliminating $I_{bsh}$ from Eqns. (4) and (5) and substituting symmetrical components for the phase voltages and currents, we get

1. $K_1 V_+ = K_2 V_-$  
2. $V_l/I_l = -Z$

where,  
$Z = (K_1 K_4 + K_2 K_3)/(K_4 K_5 + K_3 K_6)$  

Eq. (18) describes that, for a given values of shunt capacitance $C_{bsh}$, series capacitance $C_{se}$ and prime mover speed, the three phase SEIG viewed from the single phase load terminal can be represented by a single phase circuit shown in Figure.

In this circuit, $X_m$ and $F$ are the unknown quantities. The loop equation is written as

1. $(Z_l + Z) I_l = 0$

where, $Z_l = R_l + jF X_l$ is the load impedance.

Under steady state condition $I_l$ can not be equal to zero, hence

1. $Z + Z_l = 0$

Now Eq. (20) can be solved by using any numerical technique.
4. Results and Discussion

In the results presented here, predicted characteristics are shown by solid curves and experimental results are shown by points. At first, the selection of shunt and series capacitance are investigated. Once the value of capacitor elements are chosen, the steady state performance of the system is predicted. Finally, the effect of series capacitance on the voltage regulation, current and voltage in the phase windings of the three phase SEIG delivering safe output power are investigated.

4.1 Selection of Shunt Capacitor

The shunt capacitor connected across the phase b-c supplies the exciting current for no-load excitation of the machine. Thus, the suitable value of shunt capacitor $C_{sh}$ is selected first by studying the variation of no load terminal voltage with $C_{sh}$. Fig. (2) shows the variation of no-load terminal voltage with $C_{sh}$ when the machine is driven to a speed of 1.05 p.u. The terminal voltage increases with $C_{sh}$ and the rate of the increment in the voltage is reduced at higher voltage levels where the machine enters higher level of saturation.

The value of $C_{sh}$ that gives the no-load terminal voltage of 1.0 p.u. is selected as shunt capacitance and it is 35 $\mu$F.

4.2 Selection of Series Capacitor

At no-load condition, there is no current through $C_{se}$ and only $C_{sh}$ is effective in the circuit. But both $C_{sh}$ and $C_{se}$ are effective when load is being supplied. Thus, the operating constraints such as full load voltage regulation, voltage unbalance factor, and power output capacity of the machine are taken into account for selecting the optimum value of the capacitance $C_{se}$.

The effect of $C_{se}$ on the machine terminal voltage, voltage and current unbalance factors when machine is operating at rated load condition are depicted in Figs. (3a,b,c,d).

It is observed that the voltage regulation, voltage and current unbalanced factors are very sensitive to the capacitance value of series capacitor $C_{se}$. Fig. (3a) shows that the voltage regulation, which is defined as the percentage change in the load voltage as the generator delivers power from zero to rated value, is minimum for the $C_{se}$ value of 120 $\mu$F. The voltage regulation should be restricted in permissible limits, say ±6%. The voltage and current unbalanced factors, defined by ratio of negative sequence component to its positive sequence component, are minimum for the value of $C_{se}$ between 110 $\mu$F to 120 $\mu$F. Since the current unbalanced factor is the indication of negative sequence component flowing in the machine, the higher value of current unbalance causes more copper loss in the machine. Hence, the series capacitance should be selected in the range of 110 $\mu$F to 120 $\mu$F with view to limit the temperature rise of the machine. The
results depicted in Figs. (3a,b,c,d) show that there is no significant change in winding currents for the values of $C_{se}$ above 120 $\mu$F and the machine terminal voltage rises above 1.06 p.u., the permissible limit, for the value of $C_{se}$ below 120 $\mu$F. Therefore, the value of the series capacitor is selected as 120 $\mu$F in view of the minimum voltage regulation and minimum loss factor.

### 4.3 Performance Characteristics

Having identified the optimum value of series capacitance, it is considered important to know how best is this selection in respect of the other relevant performance indices of the machine. One of the main criteria to be considered is that the machine should deliver the maximum safe power at the desired voltage level without exceeding the electrical and magnetic loading of the machine. The frequency of the supply should also not fall below the minimum permissible value. Fig. (4a,b,c) displays the variation of machine performance such as load terminal voltage ($V_L$), per unit frequency ($F$), loss factor ($f_{loss}$), voltage unbalance factor ($VUF$), and winding voltages and currents with power output.

It is observed from Fig. (4a) that it is possible to obtain almost a flat load characteristics with excellent voltage regulation. The load terminal voltage is 1.03 p.u. at rated power output. The loss factor initially decreases with load and then increases, reaching rated value (1 p.u.) at rated power output. The frequency of generation also changes from 1.05 p.u. to 1.01 p.u. when the generator is loaded from no load to rated power. However, at the rated power output, the current flowing through phase b and phase c winding are higher than the rated current of the machine. The unbalance condition prevailing in the system is responsible for flowing of more than rated current in the phase b and c. This condition results in localized heating of the windings thereby necessitating derating of the SEIG. Fig. (4c) shows that the machine is required to derate to 0.84 p.u. of its rated power in order to restrict the phase currents with in the rated value.

### 5. Summary and Conclusion

The investigation has been performed to supply single phase power from a three phase SEIG for remote areas. In order to get single phase power from three phase SEIG, partially balanced operation scheme is used. Partially balanced operation scheme requires.

The Shunt and Series capacitor configuration results in self voltage regulating feature of the system. Machine operates in more balanced conditions at higher loads. Selection of the capacitors for shunt and series capacitor excitation reveals that the value of the series capacitance is
approximately three times the shunt capacitance. The safe power output that a three phase SEIG can deliver to the single phase load is approximately 84 percent of its rated capacity.

The Shunt and Series capacitor excitation has a better performance due to the following reasons.

(i) The flat load characteristics shows that the one shunt and one series capacitor configuration offers high overload capability. Hence the system is more stable at overloads.

(ii) The loss factor remains within reasonable limits throughout its operating range, i.e. from no load to rated load conditions. Thus, this configuration is suitable for both constant and variable power output applications.

So it can be concluded that a three phase SEIG can supply single phase power for remote areas, if situation demanded with Shunt and Series capacitor excitation scheme.

5.1 Conclusions

A three phase SEIG can be used to give single phase supply if situation demanded. Single phase power can be given up to the 84% of the rated capacity without burdening any phase if two capacitors of particular values is connected in series and shunt position.

REFERENCES