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LOW COST APPROACH FOR USING INDUCTION MOTORS AS GENERATORS ON STAND ALONE HYDRO SYSTEM (SAH)

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Abstract: Stand Alone Hydro System (SAH) is an Innovative Sustainable Operating Systems which running continuously to give uninterrupted electricity supply with energy storage system. This paper describes a new approach to controlling induction generators on SAH. The turbine power-speed characteristic and the relatively high magnetic saturation of modern induction machines are used to reduce the control equipment required. The implementation of the control approach is described along with considerations regarding generator selection and efficiency.

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1. Introduction

Stand Alone Hydro (SAH) system have an output range from 50kW up to 10MW. They are usually installed to supply non-interrupted electricity in remote areas which the grid fails to reach. By using appropriate designs, local skills and local manufacture these schemes can be more cost-effective than large hydro projects [1]. By using self-excited induction generators rather than synchronous generators cost savings and reliability improvements can be achieved, due to the simple construction and inherent robustness of cage induction machines [2]. However, until recently the extra cost and complexity of the voltage and frequency control equipment has more than offset the advantages of using induction generators. Fig.1 shows the compounded annual growth rate (CAGR) 212-2019 in Malaysia [3] which shows that small hydro contribute to 3.0% total growth from overall CAGR. 1.

Discussion

2.1 Control Requirement

With SAH systems, it is a self-contained system with no conventional river or water stream is required. The installation of the system can be two type which is in series installation or parallel installation as shown in Fig. 2 and Fig. 3.

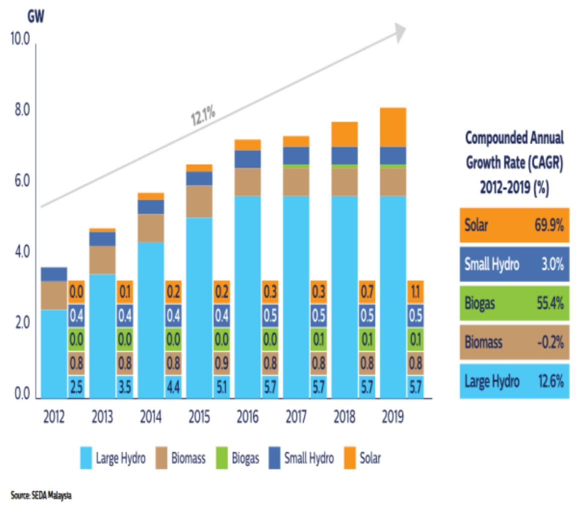

Fig.1: Overview of Malaysia's renewable energy 2012-2019 [3]

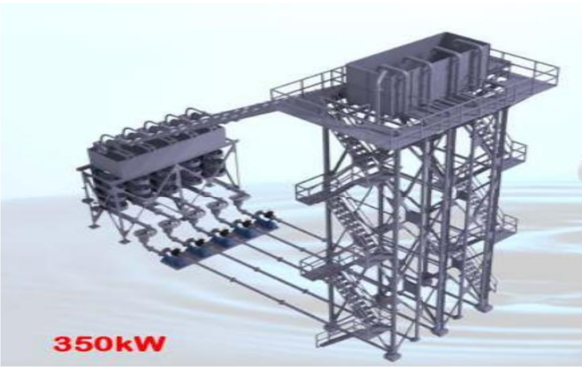

Fig. 2: Series Installation of SAH System

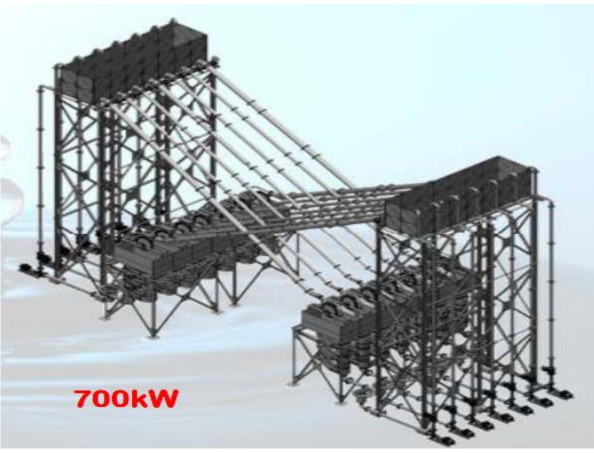

Fig.3: Cross Installation of SAH System

The turbine speed must be controlled in order to regulate the generated frequency [6]. If a synchronous generator is used, the frequency is generally controlled by means of an electronic load controller (ELC). As shown in Fig. 4, the ELC compensates for variations in the main load by automatically varying the amount of power dissipated in a resistive load, known as the 'ballast' load, in order to keep the total load constant. With synchronous generators, voltage control is not required because modern machines contain an inbuilt voltage regulator. This is not the case with an induction machine. Voltage regulator units have been developed for induction generators, which control the voltage by means of a Voltage Ampere Reactive (VAR) source [4,5]. Since these units control large reactive currents they are relatively expensive and complex for use with SAH system. The additional cost of the voltage regulator units, along with their complexity, have tended to outweigh the advantages of using induction generators for SAH system.

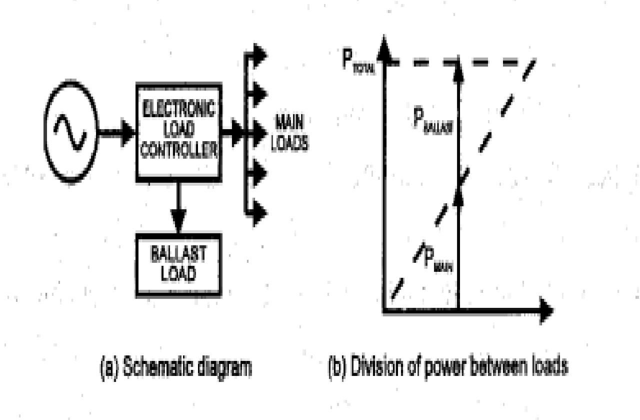

Fig.4 : Basic principal of electronic load control.[6]

2.2 New Control Approach

The separate voltage regulator units for induction generators can be designed out of the system by using the intrinsic characteristics of the turbine and induction machine [6]. Both the turbine-power-speed characteristic and the relatively high magnetic saturation of modern motors are used to advantage. As shown in Fig. 5, for constant voltage operation of an induction machine a small increase in frequency will result in a significant reduction in magnetising current. In addition, extra variable VARs are produced by the excitation capacitors due to reduced impedance. The combined effect of reduced 'magnetising current and increased leading VARs, which results from high frequency operation, can be used to advantage for power factor correction of lagging power factor loads, the function previously performed by the voltage regulator unit.

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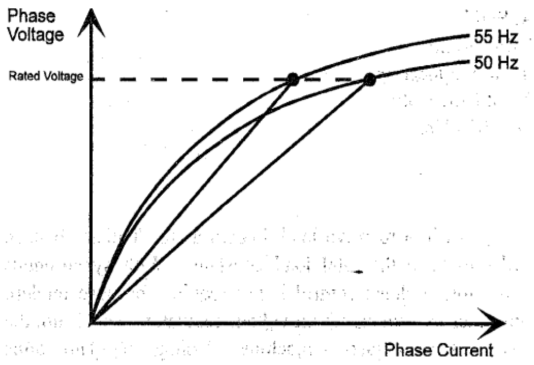

Fig. 5: No load excitation characteristics for an induction machine operated at two different frequencies.[6]

SAH's turbines are classified as impulse and reaction machines. All standard types of impulse turbine have power speed characteristics similar to shown in Fig. 6. The turbine and drive system are designed so that the turbine operates at the speed which produces maximum power output for the head and flow available. As shown in Fig. 6, small variations in speed about the maximum power output speed have little effect upon power output. All common types of reaction turbine power-speed characteristics at close to output. Hence, the small increase in turbine speed required to enable the generator frequency to rise leading VARs to compensate for inductive effect on the power output of the system.

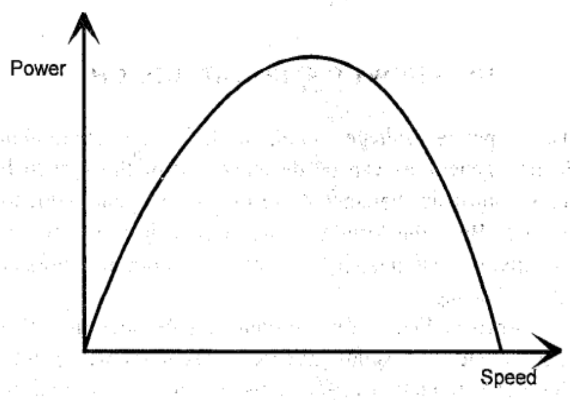

Fig 6: Typical power-speed characteristic for an impulse turbine [6]

With the new control approach, both voltage and frequency can be controlled by a load controller similar to the ELC required synchronous generator systems. The units are called Induction Generator Controllers (IGC) and are no more complicated or expensive than ELCs. Unlike the ELC they sense and directly control voltage rather than frequency [6].

When an inductive load is connected to the generator the voltage, will decrease and the IGC will respond by reducing the ballast load. The reduced load will cause an almost instantaneous frequency increase due to reduced slip and an additional gradual increase in frequency due to rising turbine speed. The rising frequency results in an increasing voltage and corresponding increasing load. A stable operating point will be reached when the load on the turbine has increased sufficiently to match the power output of the turbine [6].Since modern induction machines tend to be highly saturated, the frequency regulation with variation in load power factor is small. Sample results for a 2.2kW machine give a frequency increase of 6% for an overall load power factor of 0.9 lagging [7].

2.3 Implementation of New Approach

Three techniques for varying the ballast load were considered when designing the IGC. These were phase angle control, switched binary-weighted loads and variable mark-space ratio chopping [6].

The first techniques is by phase angle control, the power dissipation in the ballast is varied by controlling the delay angle, -, before the ballast is switched in by means of a triac or thyristor arrangement, as shown in Fig. 7. Phase angle control is often used with synchronous generators but is less appropriate for induction generators, because of the variable lagging power factor produced as a result of the ballast current lagging the voltage. This increases the frequency variation already present due to lagging power factor main loads.

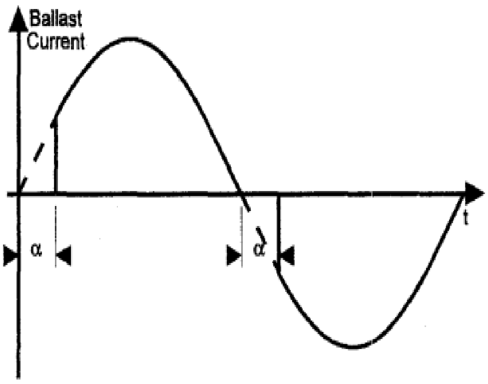

Fig.7 : Ballast current waveform for a phase angle controller[6]

Second technique is by Binary-weighted controllers switch in fixed steps of resistance, as shown in Fig. 8. They have the advantage of producing a unity power factor ballast and they do not cause any waveform distortion. The main disadvantage of binary

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weighted controllers for micro-hydro schemes is the complexity resulting from using a number of ballast loads, each with its connections, wires and switching device[6].

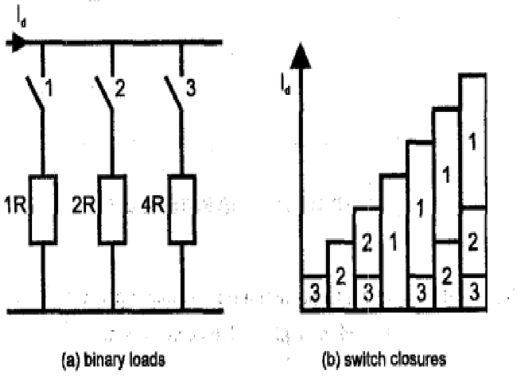

Fig. 8: Binary-weighted load controller and ballast current range

While the last techniques is by variable mark-space ratio chopping for the IGC to produces a variable unity power factor load with just a single ballast. The basic switching circuit and ballast waveform are shown in Fig. 9 and Fig. 10. Waveform distortion resulting from the chopping action is reduced by the action of the excitation capacitors.

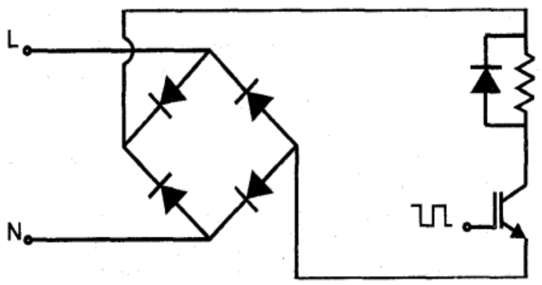

Fig. 9: Basic switching circuit for a single-phase mark-space ratio controller.

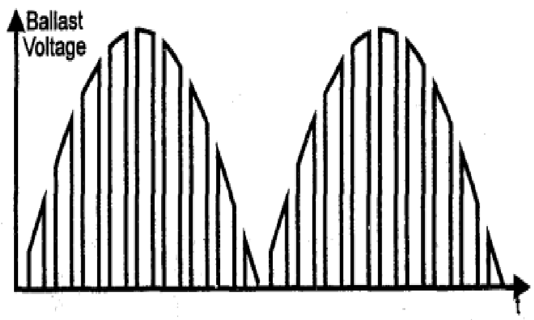

Fig.10 : Typical ballast voltage waveform for a single-phase mark-space ratio controller with 60% on time.

2. **Results**

3.1 Generator Configuration

A. Three-phase generating systems

Three-phase induction motors can be used directly as three-phase stand-alone generators, though care must be taken to ensure that the winding voltages are compatible with those of the loads to be supplied. For example, motors connected for 400 Volt delta connection cannot be reconnected in star and used as 400 Volt stand-alone generators because the machine will not be sufficiently saturated to give stable operation [8].

B. Single-phase generating systems

Single-phase induction motors can be used as generators, but problems can be experienced in determining the size and arrangement of capacitors required to achieve excitation without overloading the windings. In addition, single-phase induction motors are more expensive than three-phase induction motors and are only available for relatively small power outputs.

It is possible to use a three-phase induction motor as a single-phase generator with on 10 to 20% power de-rating, and this has become the preferred approach to providing a single-phase supply. The arrangement shown in Fig. 11, known for obvious reasons as the 'C-2C' connection, is commonly used due to its simplicity. It can be shown that for a purely resistive load, if the condition in (1) is met, the IC-2C' connected generator behaves as a balanced three phase machine [9]

$$I_r = \sqrt{3}\, I_c \qquad (1)$$

where I_r is the resistive load current

I_c is the current in the 'C' value of capacitance

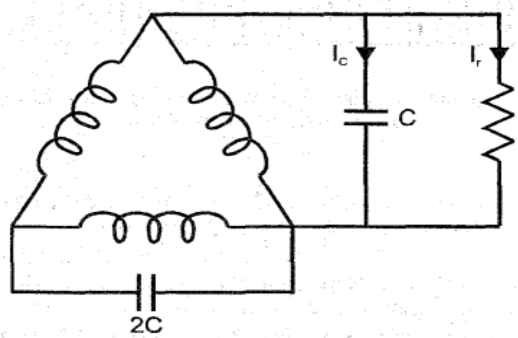

Fig.11: Single-phase generation from a three-phase machine using the 'C-2C' connection

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As efficiency comparison between the 'C-2C' and balanced three-phase delta connection was performed for a standard GEC 2.2 kW, 4 pole, TEFV 220/240 Volt delta connected motor. The resulted are stipulated in Table 1 and Fig.12 below[6].

Table 1: Generator Performance between delta 'C-2C' and balanced three-phase delta connection (50HZ and 230V) [6]

CONNECTION	LOAD (% MOTOR RATING)	CAPACITANCE (µF)	EFFICIENCY %
BALANCED DELTA	25	47	65.6
	50	52	74.2
	75	58	75.8
	100	66	75.9
C-2C	25	43	64.3
	50	50	73.9
	75	58	75.8
	100	67	75.6

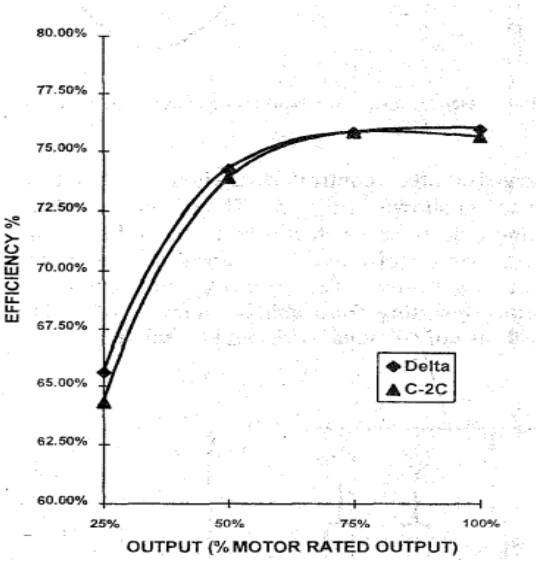

Fig.12: Efficiency against power output for single-phase 'C-2C' and balanced three phase delta connection [6]

The balanced condition (1) occurs at 75% of rated output. This is confirmed by the results which show equal efficiency for both the 'C-2C' and balanced delta connection. Either side of 75% output the 'C-2c' connection has a slightly lower efficiency due to the current imbalance in the generator windings. The effect is most significant at low power outputs. This will only be important in practice if flow variations at the hydro site mean that the turbine must sometimes be operated at much less than its design flow[6].

3.2 Improving Generator Efficiency

When an induction motor operates as a generator the power flow, and consequently the in-phase component of the stator current, are reversed. As a result, the direction of the voltage drop across the stator winding resistance and leakage inductance changes and the air gap emf increases. This in turn results in an increase in magnetising current and a consequent increase in stator and core losses. As a result the efficiency of the induction machine is lower when operated as a generator than when operated as a motor. A previous paper [10] describes how the efficiency of induction generators can be improved by increasing, the number of turns on the stator windings in order to reduce the magnetic saturation.

3. Discussion

Nowadays, towards Zero Carbon Emission, SAH is one of the most important technology for green concept, since it replaced the fuels such as gasoline oil or diesel. Hence, a simple low cost approach for using induction motors as generators on SAH can be implemented. It has the advantage of not requiring a separate variable VAR source to compensate for inductive loads. The new approach has the disadvantage of requiring small increases in frequency to compensate for lagging power factor loads. However, this can easily be achieved with a hydro turbine and provided that the frequency increase is 10% or less it is acceptable for most common loads. The suitability of this approach is demonstrated by its successful implementation in a number of countries [6].

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