Chapter 19

Operational Challenges of Low Power Hydro Plants

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This chapter discusses the electrical circuits and operations of low power hydro plants. Mainly small hydro and micro hydro power plants are covered. Both the grid connected and islanded operations are summarized. Grid connection issues and power quality problems are explained with some examples. Especially in the case of small hydro power plants, operational problems and solutions through strengthening its grid connection codes are enlightened. Finally in the case of micro hydro power plants, their electrical circuits are illustrated in details. Circuits used to obtain single phase output from a three-phase machine with machine optimized operation, electronic load controllers to maintain voltage and frequency are discussed.

19.1 Introduction

Before the industrial revolution, firewood and coal were the main sources of energy. As late as in 1890 oil constituted a mere figure of the energy market. However, with the implementation of oil based industrial applications, oil consumption grew up.

In the case of hydro power plants, the increasing power demand was compensated by building large hydro plants. However, during the last decade it was found that mostly no more potential sites were available for large hydro power plants. Further increasing environmental constrains and rapid development of Renewable Energy (RE) and Distributed Generation (DG) technologies,[1] the low power hydro plants were potentially identified as good solutions.

The severe energy crisis in the last decade forced the world to pay attention on RE Sources. Today many countries' energy policies are stressing to increase the renewable energy penetration from about 10% to 30% of its generation. Some countries like UK, USA, Spain, Denmark, Germany, Sweden, India and Sri Lanka, made policies on renewable energy as mandatory with a penetration target. Also they are supported with increased tariff and relaxing power purchase agreements with Government subsidies.

Figure 19.1 shows one unit of a 2×1 MW mini hydro power plant. For example in Sri Lanka when considered only small hydro power plants,[2] it has increased from 0.12 MW in 1996 to 100 MW in 2006 and it increased further to 125 MW in June 2008 (total country power generation is about 2 GW). However, effective and efficient operation of small hydro plants is challenging when tripping occurred at the low voltage networks. Also the plant utilization is restricted when the grid voltage violates its limits.

Off-grid power generations are one of the major technologies used in small scale RE power systems. This is very important to develop the rural areas in an economical manner with a properly coordinated electrification plan. Initially the rural areas, where less population occurs and the grid expansion is very expensive, are electrified with the off-grid. The off-grid micro hydropower generation is the

Fig. 19.1. Small hydro power plant (one unit 1250 kVA).

Fig. 19.2. Micro hydropower plant (25 kW).

economical solution to the rural electrification of the countries, which have highly hydro resources spread by streams.

Figure 19.2 shows a 25 kW micro hydro plant operated islanded mode. For example, in Sri Lanka there are about 200 micro hydropower projects that can be seen especially in the tea plantation lands.[3] The off-grid technology has already electrified about 1.2 MW proving power to about 4500 households in rural areas till June 2008. In the case of off-grid technology, a cheap and automatic voltage and frequency control of the plant is required. Even though this control circuits are available in the market, it needs to be improved further more with research and development. This will allow to run the system smoothly with unman operations.

This chapter presents an overview of the hydro plants, and discusses challenging technical problems related to plant operations, network integration and their solutions in low power hydro power plants. Mainly it is focused on: (1) network operations on voltage violation and reactive power control of the grid connected small hydro power plants and (2) single phase supply from off-grid micro hydro power plants and its power control.

19.2 Low Power Hydro Plants

19.2.1 *Categories*

Categorizing the hydro plants vary in different countries based on their total power generation. In small countries where 2 GW is the total power generation, the low power hydro plant schemes are classified into (1) small hydropower projects, which are more than 10 MW, (2) mini hydropower projects, which are from 300 kW to 10 MW and (3) micro hydropower projects, which are less than 300 kW.

In addition based on their operational features, there are two categories of hydropower schemes according to the use of water:

(1) Storage scheme: this blocks the river flow and makes a reservoir using a dam. Water will release when power generation is needed.
(2) Run-of-river scheme: here the river flow is diverted through a channel and a penstock line to the turbine for power generation.

There are many advantages on the run-of-river scheme such as (i) low cost, as the bigger dams are not involved, (ii) simplicity gives a long-term reliability and (iii) environmental friendly, as river flow patterns of downstream is not violated and no flooding of the valley upstream of the project. However, only one disadvantage is that water does not reserve extra water from rainy seasons to the dry season.[4,5]

19.2.2 *Important components*

Figure 19.3 shows the important components of a small hydro power plant. The main components of a low power hydro plant are a weir and intake structure such as desilting and forebay tank, penstock, powerhouse, tailrace, control structure with spill way, generating plant with a set of turbine-generator unit, a step-up transformer and a transmission line if it is required to connect to the National Grid.

Designs of these components are very well explained in several books and technical papers.[6,7] However, the interconnection issues and technical information related to optimizing the small hydro power plants are not well addressed in past literatures. Commonly the small hydro plants are connected to the distribution systems therefore in terms technical connection requirements, they fall under the category of Distributed Generations (DG).

19.2.3 *Interconnection issues*

These low power hydro plants are normally taken as DG types. There are many possibilities for interconnecting the DG type power plants with the power system grid. The complexity of the DG operation generally depends on the level of interaction with the existing network, especially on voltage control issues. Mostly due to over voltage problems, the DGs are unable to utilize to get their maximum power. When DG pumps active power through distribution lines it increases the terminal voltage due to more resistive line impedance. Therefore voltage control through reactive power control is mostly recommended. Few DG interconnections are explained, which are related to the low hydro power plants.[8–10]

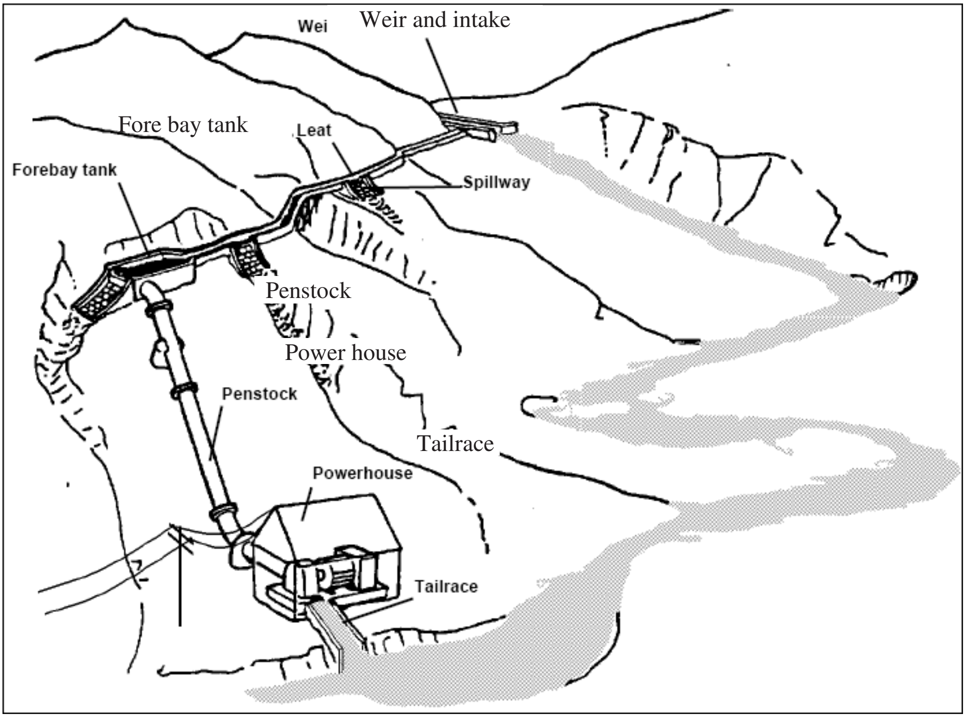

Fig. 19.3. Important components of a small hydropower plant.

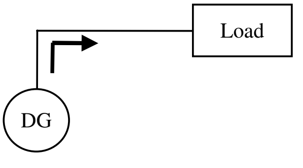

Fig. 19.4. Stand alone DG connection.

(a) *Isolated standalone power plant*

Figure 19.4 shows the stand alone DG connection. In this case the load is met by DG only and no network connection with the grid network. This is more suitable for micro hydro level of power plants. Here the voltage and frequency control must be engaged at the DG. This is more suitable where the national grid extension is very expensive and the required area is very far from the grid network.

(b) *Network support is used as back up*

Figure 19.5 shows the DG connection where the network support is used a back up supply. DG provides power to Load 2 (part of the total load). The network covers

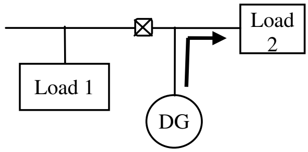

Fig. 19.5. Isolated system with automatic transfer.

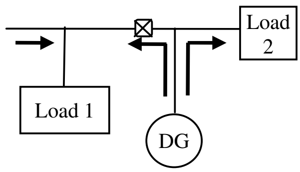

Fig. 19.6. DG connected to the network with no power export.

Load 1 and 2 when needed. DG does not need to be operated with the network in parallel. Here the DG must be engaged with frequency and voltage control. Mostly the loads in the "Load 2" section are based on passive loads, which will not be very sensitive to the frequency of the supply. The automatic or manual transfer switch can be used based on the facility required and type of DG.

(c) *Connected to the network without exporting power to the network*

Figure 19.6 shows the DG connection where it is connected to the network but not exporting power to the network. DG provides power to Load 2 and partially to the Load 1. The network covers balance of the Load 1. Here the DG may be engaged for voltage control based on the grid code requirements. DG need not to contribute to frequency control. The maximum load in the "Load 2" section is less than the DG's maximum power while the minimum of the total load is higher than DG ratings. Therefore here the DG will not pump any excess power to the grid so that there would not be any reverse power flow in the grid network. This minimizes changes in the grid protection system.

(d) *Connected to the network with exporting power to the network*

Figure 19.7 shows the DG connection where its agreement supports for the export of power to the network. Therefore here the DG provides power to Load while exporting extra power to the grid network. There are two types: (i) always exports power to the network, where DG rating is higher than the load and (ii) exports power only when excess power is available. DG may be engaged for voltage control based on the grid code requirements. But it is recommended to go with voltage control wherever required so that the DG can be properly utilized as its power export needs

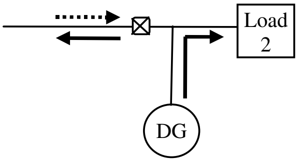

Fig. 19.7. DG connected to the network with power export.

not to be constrained by network voltage limits. This kind of DG connection is beneficial to the utilities. For example, if the system peak load is from domestic loads, if this DG is operated with an industry which is not operated during the peak time (closing down by 5 pm), then the DG supports level the system load by double factor, so that the transmission network utilization becomes very high and thus the payback is reduced. The attractive payback catches the attention of transmission line infrastructure development.

(e) *Stand by operation or peak load operation*

Figure 19.8 shows the DG connection where it is used for peak load operation or back up generation. This type of DG connection is mainly used to the sensitive industrial loads to avoid disturbance during any power failures. Some industries use DG to supply their demand during peak load period. This is mainly dependant on the utility electricity tariff. If the tariff is too high during the peak load period then industries go for this arrangement. In this category, the industrial load is connected to DG or utility at once. DG will not operate in parallel with utility supply. The DG operating time will be minimal.

(f) *Connected to the network exporting power to the utility*

Figure 19.9 shows the normal DG connection. Here the DG is connected to the network all the time and exports power to the utility. DG may be engaged for voltage control based on the grid code requirements. This concept does not include

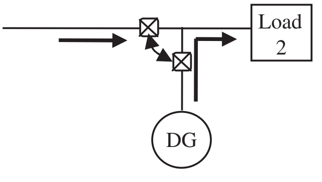

Fig. 19.8. DG operated as stand by or during peak load period.

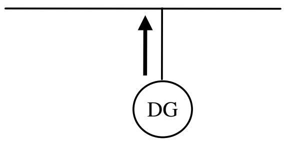

Fig. 19.9. DG connected to the utility network with power export.

any industrial loads. This is mainly dealt with Utilities through Independent Power Producers (IPP) agreements. This kind of DG connection is also beneficial to the utilities by minimizing the transmission losses. Here the DGs are allowed to install closer to the load centers and operate in parallel to the grid network. The DG operation is fully determined by the utility rather than industries.

19.2.4 *Operational challenges and grid code requirements*

The DGs are connected to the low voltage networks, where the load varies frequently and rapidly. Further, the Small Hydropower Plants (SHP) are located in rural areas, where the grid network is very weak, far in distance and mostly depend on low voltage networks. It will be experiencing several tripping happening in the network mainly due to tree touching. Therefore additional care should be taken on voltage control at steady state operations. The transient operation must be considered especially on fast load rejection due to frequent tripping of the low voltage grid network.[7]

The SHPs are usually operated according to DG concept in a voltage-following mode. Therefore the DG will not attempt to control the network voltage. However the power injection into the network changes the voltage as a result of current flows through the system impedance. These changes create interactive operations with the existing utility voltage control equipment such as Load Tap Changers (LTCs) and feeder regulators.

Figures 19.10 and 19.11 show a scenario, where a DG at downstream of a regulator can cause low voltage at the end of the circuit due to the use of line drop compensation on the regulator. Here the load along the feeder is also assumed as gradually decreasing due to power distribution. The power injected by the generator

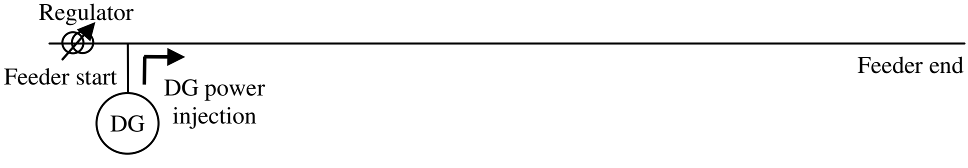

Fig. 19.10. Circuit configuration with the DG at downstream of a regulator used to analyze the voltage along the feeder.

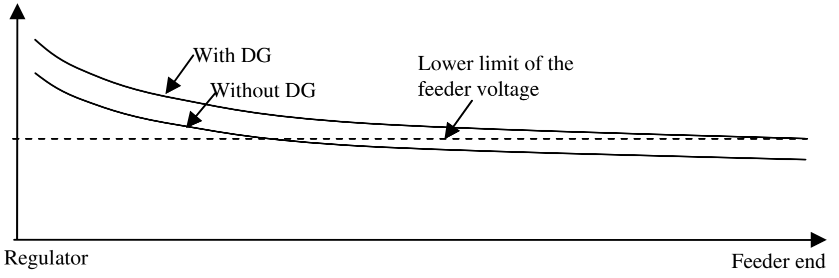

Fig. 19.11. Voltage distribution along the feeder with and without the DG.

will not allow the regulator to properly act for the voltage changes. In the case of reverse power flow the regulator can change all the way to the lowest tap, which would cause very low voltage at the downstream feeder end.

To overcome the voltage problem the SHPs can be operated together with the voltage control devices in the distribution system through proper coordination. This will allow the DG to export power without violating the feeder voltages. To achieve this some options are listed: (i) To reduce the line drop, raise the compensator voltage set point slightly. This moves the regulator constant voltage point closer to the regulator and reduces the impact of the DG, (ii) if the reverse power flow causes the voltage violation then advance regulator controllers can be used to change the operating mode, (iii) moving either the generator or the regulator can also be considered at the planning stage, so that the regulator is placed at the downstream of the generator, (iv) installation of a new regulator can also be an option, especially if the DG is large relative to the feeder capacity, (v) another consideration is widening the regulator bandwidth setting, which reduces the line drop compensation. Increasing the time delay can also help to prevent excessive regulator tap changes, depending on the rate of change of the DG's energy source, (vi) if possible, integrate the DG closer to the feeder end. This will solve any problem due to low voltage at the feeder end. However a proper study must be made at the planning stage to find the best option for a case.

19.3 Micro Hydro Plants

19.3.1 *Overview*

Boosting the economy of a country is mainly achieved by providing electricity to all nations. A major challenge to achieving this target is providing the electricity in an economical way to the rural areas, which are far away from the national grid and the houses are spread widely. Further fossil fuel operated generations are also not wanted according to the environmental constraints. Therefore the stand alone operated micro hydro plant concept was used as a potential energy source especially when there are small waterfalls or rivers. Sri Lanka is one of very good example country for the off-grid electrification. According to Renewable Energy for Rural Economic Development (RERED) project reports,[11] the off-grid technology has already electrified about 1.2 MW, providing power to about 4500 households in rural areas till June 2008. In the case of off-grid technology, a cheap automatic voltage and frequency control of the plant is one of the important section that needs to be developed. This will allow to run the system unman and smoothly.

19.3.2 *Micro hydro generation technology*

In micro hydro schemes, either synchronous or induction machines can be used as the generator. Due to the simple construction, robust operation, wider availability and cheap cost, induction generator sets are much popular in micro-hydro industries. Further single phase network is more economical than a three phase network in rural areas. Therefore generally three phase induction generators are used with well known C-2C arrangement to obtain a single phase output while maintaining the balance operation in the machine.[12]

Figures 19.12 and 19.13 show the C-2C circuit configuration and phasor diagram of the voltages and currents in the circuit. Here the single phase load is connected across the terminals *a* and *b*. Therefore the total output power is same as the single

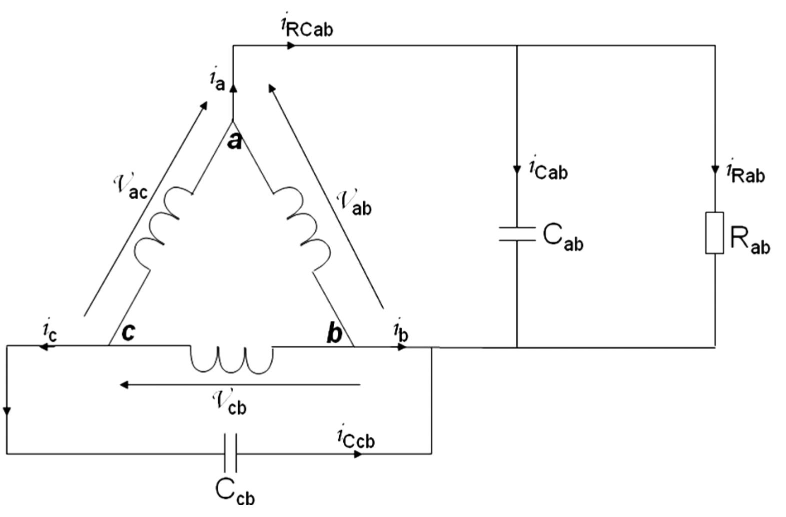

Fig. 19.12. C-2C circuit configuration to obtain the single phase supply from the three phase induction generator.

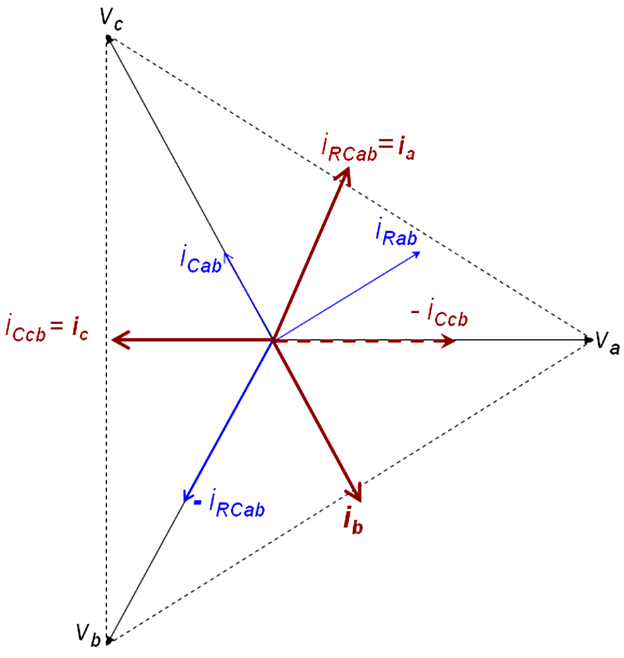

Fig. 19.13. Phase diagram of the current and voltages in the C-2C circuit configuration.

phase power that can be written as:

$$P_{total\_1\phi} = v_{ab} \times i_{Rab} = V_{LL} \times I_{LL} \times \cos 30^\circ. \qquad (19.1)$$

Further, it can be proved that in order to make the load on the machine to be balanced, the angle between the i_a and the i_{Cab} should be 60°. Then the angle between the i_a and i_{Rab} should be 30°. Then i_{Rab} can be written in terms of i_a. Therefore the total power can be written as

$$P_{total\_1\phi} = v_{ab} \times i_a \times \cos 30^\circ. \qquad (19.2)$$

Hence, the power delivered by the machine becomes 50% of its ratings, as shown below, when C-2C configuration is used.

$$P_{total\_1\phi} = \frac{1}{2} P_{total\_3\phi}. \qquad (19.3)$$

This is the only drawback of the C-2C configuration. However, it simplifies the required number of electronic controllers to be one with a single phase arrangement. Therefore this configuration is mostly used in many micro hydro scale generating schemes especially with islanded operation.

19.3.3 *Load controllers used in micro hydro generation technology*

Normally, a mechanical governor system is used to match the input power to the turbine according to the load demand. However due to its complexity, a new mechanism of Electronic Load controller (ELC) came into the industry and became very popular.[13] In ELC, the load is controlled using electronic devices. This maintains a constant electrical load on the generator in spite of change in user loads. ELC uses a ballast load to damp the extra power that is not required by the users, so that it maintains the constant load on the generator. This permits the use of a turbine without governor control system if it is supplied roughly with constant head and water flow. Hence the ELC maintains the machine speed. However, it has been reported that in micro hydro systems, ELC fails very frequently and requires frequent maintenance. Hence, in order to develop a robust ELC system, a thorough understanding of the effects of the variations of the various parameters on the system is a necessity.

19.3.4 *Recent developments on micro hydro generation technology*

Failures of electronic ballast were suspected due to risk on the control techniques used. The traditional control technique uses only the load current and tries to keep the load constant. Studies have been done to accommodate the generator speed and terminal voltage to this traditional control technique. The addition of speed and terminal voltage parameters makes more stable control with solid determination on the system status. However, this also makes the control technique complicated with many input parameters.

In case of C-2C configuration, it was proven that its utilization is only 50% of the machine rating. Recent researches are focused on increasing its utilization. Therefore a new technique to generate two phase power from a three phase generator using C-2R-R arrangement is proposed.[14] This becomes more attractive as it utilizes the machine's rating up to 86.6%. As shown in Figs. 19.14 and 19.15, and according to Eqs. (19.4) to (19.7), it can be shown that with two phase output configuration, it is capable of delivering more power than that with the traditional C-2C method. Two phase loads can be connected with common delta point as neutral terminal and due to two phase configuration the total load power is increased.

$$P_{total\_2\phi} = v_{ab} \times i_{Rab} + v_{cb} \times i_{Rcb}, \tag{19.4}$$

$$P_{total\_2\phi} = V_{LL} \times I_{LL} + V_{LL} \times I_{LL} \times \cos 60^\circ, \tag{19.5}$$

$$P_{total\_3\phi} = \sqrt{3} \times V_{LL} \times I_{LL}, \tag{19.6}$$

$$P_{total\_2\phi} = \frac{\sqrt{3}}{2} P_{total\_3\phi}. \tag{19.7}$$

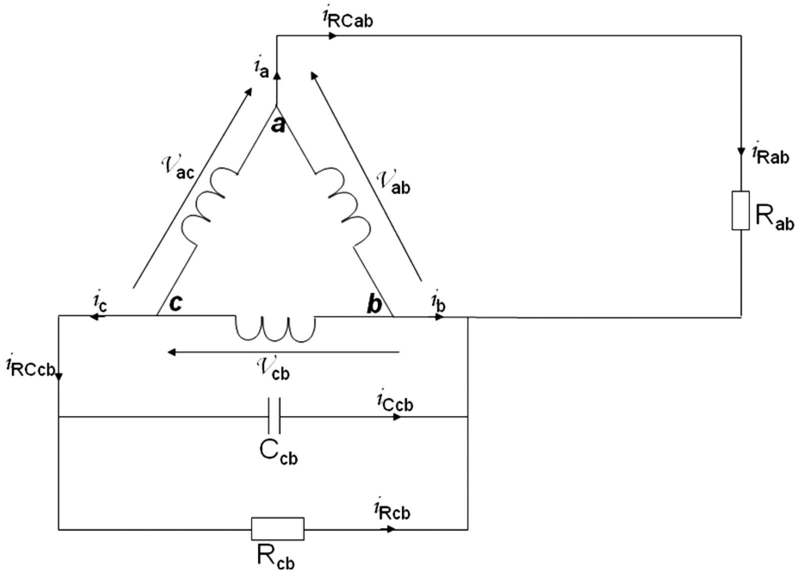

Fig. 19.14. C-2R-R circuit configuration to obtain two phases supplies from a three phase induction generator.

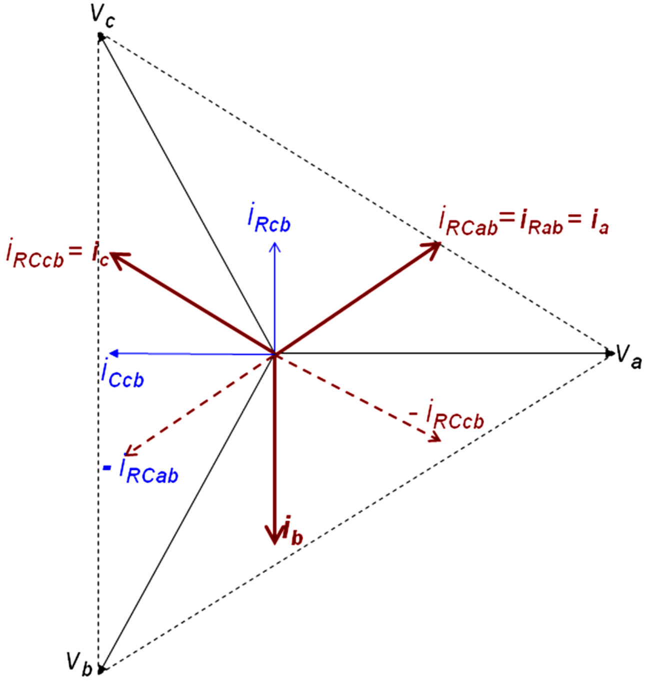

Fig. 19.15. Phase diagram of the current and voltages in the C-2C circuit configuration.

Hence, the power delivered by the machine becomes 86.6% of its ratings, as shown in Eq. (19.7), when C-2R-R configuration is used. However, this technique is still in the research and development stage as it has minimum amount of capacitors for exciting the machine. Therefore if the machine is not having enough residual flux then the starting up procedure of this configuration still seems to be complicated.

19.4 Concluding Remarks

This chapter has summarized the mini hydro and micro hydro generations. The mini hydro generation technology has been very well developed. Its connection methods are discussed in detail for the benefit of operators of both plant and the national grid. The micro hydro technology is mainly used in islanded connections. In rural areas single phase connections are more economical when compared with three phase connections. Therefore the traditionally used C-2C configuration is explained to get a single phase output from the three phase machine. Further recent research and development on this micro hydro technology is explained with a two phase output from the three phase machine.

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